Marine Fisheries
REVIEW
Vol. 68, No. 1–4
2006
United States Department of Commerce

Blue Crab

Marine Fisheries REVIEW

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On the cover: A mature female blue crab, *Callinectes sapidus*. NOAA Photo Library image. Photographer: Mary Hollinger, NOAA, NODC.

Articles — *68(1–4), 2006*

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The *Marine Fisheries Review* (ISSN 0090-1830) is published quarterly by the Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., BIN C15700, Seattle, WA 98115. Annual subscriptions are sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. The annual subscription price is $21.00 domestic, $29.40 foreign. Single copies are $12.00 domestic, $16.80 foreign. For new subscriptions write: New Orders, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

POSTMASTER: Send address changes for subscriptions for this journal to: *Marine Fisheries Review*, c/o Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. This issue, volume 68 number 1–4, was printed and distributed in January 2008.

This publication is available online at http://spo.nwr.noaa.gov/mcontent.htm

Toward a Model for Fisheries Social Impact Assessment

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Introduction

For many years experienced fisheries social scientists have discussed developing a fisheries model for social impact assessment (SIA) that would be more compatible with the approaches taken by fisheries biologists and economists when assessing potential effects of management actions. They suspected that fishery management council (FMC) members might see social impact assessments as more useful if those assessments were provided in a format analogous to fisheries economists' and fisheries biologists' formats.

This point was given further support by Sharp and Lach's (2003) survey of Federal and state fishery managers and decision makers in the Pacific Northwest. They were asked about their knowledge of how to incorporate the social values of fishing communities into planning and decision-making. The authors concluded that it is unlikely that community information can be used in fishery plan development or amendment processes when it is presented in a qualitative, descriptive format.

Stimulated by this discussion, the Office of Science and Technology of NOAA's National Marine Fisheries Service invited a group of marine fisheries social scientists with expertise in social science modeling, quantitative methods, and marine fisheries impact assessment to create a conceptual model for predicting the social impacts of fishery management action alternatives using a limited set of quantitative and qualitative indicators. The resulting model was to be suitable for social impact assessment, and it was to include a dependent measure or output that would be analogous to the economists' use of jobs, income, or total economic output in their models.

This paper presents the results of the first phase of this group's work. Well-being was selected as the dependent measure for marine fisheries social impact assessment in this model. While this model is not the only possible approach to social impact assessment, it does open a door to a room that is closer to those currently occupied by marine fisheries economists and their biologist counterparts.

Historical Background

Social impact assessment began as a field in the 1960's as people became more concerned with human impacts on the environment (Finsterbusch and Freudenberg, 2002:408). The National Environmental Policy Act (NEPA) of 1969[1] called for analyzing the impact of human actions on the environment when designated changes were contemplated. Early NEPA guidelines emphasized environmental assessment and did not require SIA's. Few government agencies had yet invested in the social science expertise to do SIA's. Social scientists, however, continued to perfect SIA methodologies (Shields, 1974; Finsterbusch and Wolf, 1977; Finsterbusch et al., 1983; Burch and DeLuca, 1984; Freudenberg, 1986; Barrow, 1997; Becker 1997; Burdge, 1994, 2004; Vanclay, 2003; Taylor et al., 2004).

Preparation and passage of the Fishery Conservation and Management Act of 1976 (now the Magnuson-Stevens Fishery Conservation and Management Act or MSFCMA, also referred to as the

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ABSTRACT—This paper presents a model for Fisheries Social Impact Assessment (SIA) that lays the groundwork for development of fisheries-focused, quantitative social assessments with a clear conceptual model. The usefulness of current fisheries SIA's has been called into question by some as incompatible with approaches taken by fisheries biologists and economists when assessing potential effects of management actions. Our model's approach is closer to the economists' and biologists' assessments and is therefore more useful for Fishery Management Council members. The paper was developed by anthropologists initially brought together in 2004 for an SIA Modeling Workshop by the National Marine Fisheries Service, NOAA. Opinions and conclusions expressed or implied are solely those of the authors and do not necessarily reflect the views or policy of the National Marine Fisheries Service, NOAA.

[1]See http://ceq.eh.doe.gov/nepa/regs/nepa/nepaeqia.htm, accessed 25 May 2006.

MSA[2]) led to efforts to gather social data and to carry out impact analysis specifically for fisheries (OSU, 1978; Acheson et al., 1980). The National Marine Fisheries Service (NOAA-NMFS, 1994, 2001, 2006), in association with social scientists, has been developing SIA approaches since the 1980's.[3] SIA methods were also being developed in other areas of resource management (Kogut, 1976; USDOT, 1982; Bryan, 1984).[4]

The 1990's brought recognition that progress on environmental problems was neither rapid nor successful in part because social and cultural dimensions of resource management were not being given sufficient emphasis. The U.S. Forest Service gathered social scientists from many agencies to develop common SIA approaches (ICGPSIA, 1994). By 1997, SIA became required in many Federal programs.[5] The Interorganizational Committee on Guidelines and Principles for SIA published revised SIA guidelines and principles in 2003 (ICGPSIA, 2003).

In marine resource management, lack of success with fishery management led to changes in the fishery management process and passage of the Sustainable Fisheries Act (SFA) of 1996. National Standard 8 of the SFA requires explicit consideration and minimization of community impacts. The NMFS (1998) subsequently published National Standard 8 Guidelines[6] and has directed efforts toward community profiling to serve as an informed basis from which to begin SIA. While economists had been on NMFS staff since its incarnation as the Bureau of Commercial Fisheries in 1956 (Hobart, 1995), and one anthropologist or sociologist had been in Headquarters since 1974, NMFS hired its first regional social scientist (other than economists) in 1992. By 2005, each NMFS region except the Southwest had at least one such social scientist, signaling a new agency effort to develop its capability to meet its obligations to examine sociocultural regulatory impacts (Colburn et al., 2006).

Objectives

Building on previous government experience and an extensive literature on SIA, our effort takes SIA for marine resource management a step further. Our goals include making SIA more quantitative and useful. First, data derived through SIA should be amenable to comparison across space and time and should be cross-referenced with biophysical and economic data.

Biophysical and economic data are typically more quantitative than the social science data currently collected for SIA. The quantitative natures of biophysical and economic data facilitate the comparison of datasets collected in disparate spatial and temporal frames. To obtain quantitative social science data for comparative purposes that can be linked with biophysical and economic data, variables need to be identified, defined, and operationalized in a consistent way, and sufficient data must be gathered to make comparisons statistically and scientifically defensible. Operationalization means measuring variables in a way that is replicable, reliable, accurate, and valid. It means the measure is comprehensible to all researchers conducting SIA.

The approach presented here emphasizes the fact that humans are an important component of marine ecosystems. NMFS has committed itself to developing ecosystem-based approaches to marine resource management[7] (NMFS, 1999), an approach compatible with the approach presented here. The current NOAA working definition of an ecosystem is "... a geographically specified system of organisms (including humans), the environment, and the processes that control its dynamics".[8] Another goal is to develop an SIA model that is fully compatible with ecosystem-based approaches to fisheries management.

Well-Being, the Dependent Measure

The SIA model for marine resource management is designed to predict changes in well-being. Well-being refers to the degree to which an individual, family, or larger social grouping (e.g. firm, community) can be characterized as being healthy (sound and functional), happy, and prosperous.

One might argue that changes in economic welfare, such as changes in income or wealth are adequate measures of well-being. Social scientists, however, have shown that fishing and interaction with marine resources is much more than solely an economic activity (Acheson et al., 1980; Anderson, 1980; Smith, 1981; McCay et al., 1993; Bunce et al., 2000). Well-being is affected by a large number of sociocultural and economic variables that are impacted by management decisions, making it a suitable measure in this context (Colfer and Byron, 2001; Eckersley, et al., 2001; Gullone and Cummins, 2002; Suh and Deiner, 2003). There is a substantial literature on this widely used construct as well as on its operationalization at the individual, community, and national levels of analysis. It has the advantage that it can be measured in multiple ways

[2]See http://www.nmfs.noaa.gov/sfa/sustainable_fishereries_act.pdf, accessed 25 May 2006.

[3]An online version for NMFS of the 1994 ICGP-SIA Guidelines and Principles for Social Impact Assessment can be found at http://www.nmfs.noaa.gov/sfa/social_impact_guide.htm, accessed 2 May 2007.

[4]See Bowen, Palmer. 1980. Social impact assessment forest planning and decision making: Technical review draft. USDA, For. Serv., Northern Region, Missoula, Mont., for an additional reference.

[5]See the United States General Services Administration's 1997 Call-in Fact Sheet at http://www.gsa.ene.com/factsheet/0397/03_97_9.htm, accessed 12 August 2005. An alternative reference http://www.epa.gov/superfund/action/guidance/SILitRevFinal.pdf, accessed 24 July 2006, contains a table comparing actual numbers of SIA's done by agency 1979–1994.

[6]See http://www.st.nmfs.gov/st1/econ/cia/sia/natstand-final.pdf, accessed 5 May 2007.

[7]See http://ecosystems.noaa.gov/whats_new.htm, accessed 25 May 2006. Current presentations on developing NMFS's ecosystem based management programs are given here.

[8]The parenthetical phrase "including humans" does not appear in the NOAA Fisheries Glossary (Blackhart, et al., 2005) definition of ecosystem (p. 11), however it has been included in the definition at least since 2003 appearing in internal memos from the NMFS Chief Scientist to others outside NMFS, and is part of the definition used in diverse presentations to diverse audiences. This emphasizes that humans are among the organisms whose behavior must be considered when studying marine ecosystems. For example see Stephen Murawski's 19 May 2006 presentation "Ecosystems approaches to management: The EGT's work in progress", online at http://ecosystems.noaa.gov/whats_new.htm, accessed 25 May 2006.

using established and publicly available indicators for different levels of analysis (Sharpe, 1999; Ryan and Deci, 2001; Sirgy, 2002; Zumbo, 2002), and it can be related to the narrower economic measures of welfare.

SIA Procedure

The first step carried out by an analyst in an SIA is a scoping process to determine the sociocultural variables relevant to the management questions (NMFS, 2001). This can lead to initial sketches of the sociocultural system that may be affected by the management action. Management actions will affect a range of social entities including individuals, firms, families, and communities[9], and therefore the SIA must attend to these as distinct units of analysis.

Special attention should be given to social groups that may gain or lose from the management choices made. These populations may not always be readily visible at public hearings or on newspaper op-ed pages. Scoping, therefore, requires an assessment of each part of the sociocultural system that is likely to be affected, with specific attention to any marginalized populations because environmental justice issues may also be involved.

Of primary concern is measuring how the well-being of system participants will change. The objective is not to include every sociocultural element in the system; it is to do an initial assessment that identifies the critical populations that have a significant stake in the management action and the issues of concern to these populations that may increase or decrease their well-being.

The next step following the scoping process is to operationalize the relevant variables by defining the variables in a way that facilitates measurement.[10]

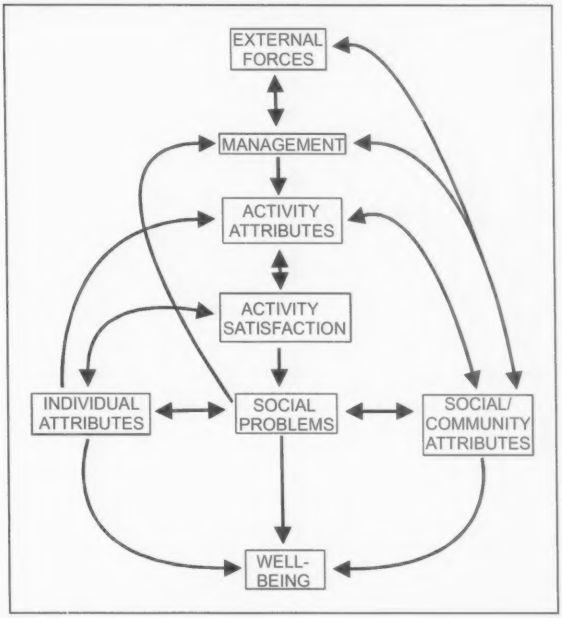

Figure 1.—General marine resource SIA model. Ecosystem does not appear as an element in the model because everything in the diagram is part of the ecosystem. It is incorrect to add ecosystem to external forces, although parts of the ecosystem are "external forces" because the community is also part of the ecosystem.

A variety of instruments available for these assessments are given in the appendix. Limited financial resources, time constraints, and staff skill level might further limit the variables and measures chosen.

More important than simply identifying variables, however, is discerning the relationships among them. This is because the impact on one variable or variable set may be transmitted to another linked variable or variable set through cumulative processes, feedback loops, and other systematic relationships. These relationships can exist both within single levels of analysis (e.g. the community) and across levels of analysis (e.g. the individual, the family, and the community). Some of these relationships are explored in the following sections.

General Fishery SIA Model

The general marine resource SIA model presented in Figure 1 depicts the sociocultural system, showing that external forces influence management strategies, which, in turn, influence human activities with regard to marine resources. These changes in activities impact satisfaction with the activities, and this influences aspects of individuals and the communities in which they live, as illustrated by the individual and social attributes (Fig. 1). The arrows in this figure reflect interrelationships (cause-effect, resonance, cumulative impacts) between these classes of variables that will be explained below as the general model is developed for commercial, subsistence, and recreational fisheries.

SIA in Three Types of Fisheries

Although there are many ways to classify U.S. fisheries, fishery managers identify three categories: commercial, subsistence, and recreational fisheries, and their subtypes. We consider how

[9]Communities can be spatial, occupational, interest-based, cultural, or ethnic. With reference to the MSA, communities designated under National Standard 8 must be place-based, but communities based on other criteria may be appropriate for the general social impact assessment required for all communities involved in fishing.

[10]It is important to note here that one of the bases for people's behavior is perception, even though those perceptions sometimes deviate from other empirical measures.

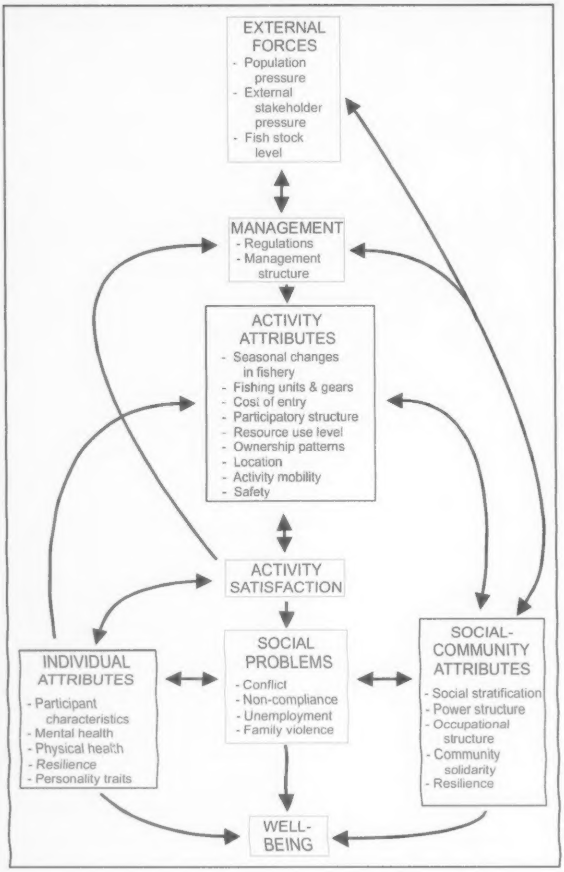

Figure 2.—Simplified fishery SIA model with selected indicators.

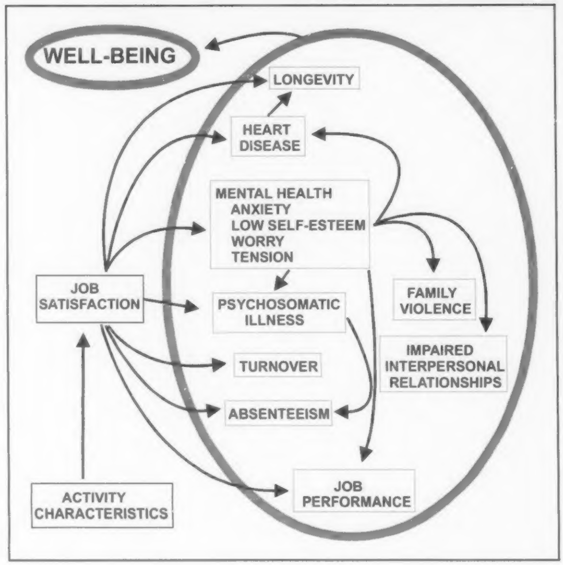

Figure 3.—Impacts of job satisfaction.

SIA can be conducted for each of these three kinds of fisheries. The examples that follow build from descriptions of the general ecosystem and illustrate relationships among variables that impact well-being. In the most general of formulations, a fishery is a system in which humans are linked to "fish."

Commercial Fisheries

First, we will examine potential impacts of management on commercial fishermen[11] and shore side entities that constitute the commercial sector (e.g. processors and dealers, ice houses, etc.), as well as the commercial sector of the marine recreational fishery, including charter boat operators, party boat operators, guides, marina operators, bait and tackle dealers, and other entities appropriate to the SIA.

The simplified model (Fig. 1) presents some rather obvious relationships, and Figure 2 identifies for illustrative purposes a few of the specific variables included in each of the general categories in Figure 1. A more comprehensive list of variables can be found in the appendix. We argue that external forces, such as population pressure, declining fish stocks, environmental activism, and climate change influence the management of fisheries. In turn, management, which can impact fishing targets, times, techniques, numbers of fishermen, and other variables (the appendix lists activity attributes) has an influence on various attributes of the occupation of fishing.

Impacts of the changes will vary according to attributes of the impacted fishery, fishermen, and community—some are more resilient (see glossary) than others. Smith et al. (2003), for example, discuss some factors influencing differential resilience of fishing families impacted by the Florida net fishing ban, and Gilden et al. (1999) discuss Oregon fishing communities' differential ability to cope in the face of complex regional changes. Individual and social resilience are complicated variables that represent an ability to cope with change, and they are related to other social and psychological variables including social support systems (both familial and external), self-esteem, and perceived control (Mederer, 1999). Additionally, Mederer (1999) notes that resilience is not a fixed attribute, but results from interaction between family and individual attributes and external circumstances.

Individual fishermen accustomed to a fishery with one set of attributes must then become accustomed to changes, some of which may impact their level

[11]Following the convention of most people who fish, we employ the term "fishermen" to denote both males and females.

of activity satisfaction and ultimately their well-being. In the instance of an occupation like commercial fishing we will refer to the activity satisfaction of individuals as job satisfaction, which is more commonly used in the literature. A great deal of research (Apostle et al., 1985; Pollnac and Poggie, 1988; Gatewood and McCay, 1990; Binkley, 1995; Pollnac et al., 2001) has linked job satisfaction to 1) individual attributes such as mental health and longevity, and 2) social problems such as family violence, absenteeism, and job performance (Fig. 3 gives a more complete list of impacts[12]).

While job satisfaction is an important aspect of all occupations, it is especially significant with regard to a fishery—including both commercial fishermen and commercial sectors of the recreational fishing industry (e.g. charter boat operators and fishing guides). The structure of job satisfaction among these groups manifests a common component[13] that is not always found in other occupations—a self-actualization component that includes "adventure" and "challenge" (Smith, 1981; Apostle et al., 1985; Pollnac and Poggie, 1988; Gatewood and McCay, 1990; Binkley, 1995; Pollnac, et al., 2001; Pollnac and Poggie, 2006).

These concepts have been described by fishermen as including the thrill of the hunt, the challenge of facing the power and expanse of the sea, and the overall adventure of pitting oneself against the elements and finding fish.

These attitudes towards the occupation of fishing are found in the U.S. east coast, Canada, Southeast Alaska (see Pollnac and Poggie, 2006), Southeast Asia (Philippines, Vietnam and Indonesia: Pollnac et al., 2001), and Central America (Pollnac and Ruiz-Stout, 1977).

Pollnac and Poggie (1980) suggest that this is an attitude shared by most fishermen. For example, in response to a question asking a sample of fishermen (n=153) from 11 villages what they like about fishing in comparison to other occupations, the most frequent response category was "sport-pleasure" (35%) followed by "income" (31%) and "independence" (16%). With regard to the "sport-pleasure" category, fishermen actually said that fishing is like a sport. They emphasized the sporting aspect of struggling with fish as well as the pleasurable aspects of being on the sea and in the fresh air (Pollnac and Ruiz-Stout, 1977).

These components of job satisfaction are related to a personality trait that serves to adapt fishermen to the dangers and risks of their occupation (see Pollnac et al., 1998 and Pollnac and Poggie, 2006 and the references therein). Overall, an extensive literature supports the contention that fishermen manifest the personality traits of being adventurous, active, aggressive, and courageous (Poggie and Gersuny, 1974; Pollnac, 1988; Binkley, 1995).

We are not arguing that it is only these personality traits that result in individuals choosing to become fishermen. They also enter the occupation as a means of making money, because their family or friends are fishermen, and/or because it is a traditional occupation in their community.

What we do argue, however, is that individuals not manifesting these personality traits would not be satisfied with the risks to personal safety and production associated with the dangers, challenges, and uncertainty of the occupation (as illustrated by the arrow from "individual attributes," which includes personality, to "job satisfaction" in Fig. 2) and would either be less efficient as fishermen or drop out of the occupation entirely (Binkley, 1995; Pollnac et al., 1998). This could then increase the percentage of fishermen manifesting these traits.

Management measures which influence aspects of fishing (e.g. quotas, time limits, numbers of days fishing available, and a myriad of other constraints on many aspects of the fishing activity), will have differential impacts on job satisfaction, ranging anywhere from negative to positive, depending on the action. Regulations that require fishermen to spend either more or less time than usual at home can impact not just job satisfaction but family life, and both are important components of well-being. Regulations requiring large capital investments can limit investments in other important areas such as vessel maintenance, the fishermen's homes, and their children's education—all impacting well-being. Changes that result in the loss of fishing opportunities, however, will have the greatest negative impacts, as alternative income projects are often problematic for this group (Pollnac et al., 2001; Sievanen et al., 2005; Pollnac and Poggie, 2006).

Social problems associated with job dissatisfaction, as well as other variables mentioned above, can impact aspects of community structure including community solidarity and levels of compliance with fishery regulations. In turn, levels of compliance can feed back and impact aspects of fishery management. Further, other aspects of community structure, such as occupational structure, can impact activity attributes. Community power structure, which might include powerful fisheries organizations, can directly influence management as well as the external forces that influence management. Finally, individual attributes, social problems, and community structure all have an effect on well-being.

A familiar example of the relationships between some of the variables in Figure 2 would be the external forces (e.g. industry organizations) that have influenced managers in some areas to implement individual fishery quotas (IFQ's) (management). In Alaska this was accomplished with the Pacific halibut (*Hippoglossus stenolepis*)/sablefish (*Anoplopoma fimbria*) IFQ program, which eliminated the short "derby

[12]USHEW (1973) gives an important early discussion on heart disease and psychosomatic illness relationships to work. Subsequent research continues to confirm a relationship between aspects of occupation or work conditions and cardiovascular disease as well as other diseases. Faragher et al. (2005) provides a recent meta-analysis of the literature on the relationship between job satisfaction and health including cardiovascular disease, and Heslop et al. (2002) is a longitudinal study of the relationships between job satisfaction, cardiovascular risk factors, and mortality. An extensive literature exists in this area.

[13]Other components found among fishermen, such as "basic needs" like safety, cleanliness, and earnings, are also commonly found associated with other occupations (per references cited in footnote 12).

fishing"[14] seasons, and spread fishing out over a longer period (activity attributes). Interviews conducted as part of a research project in Southeast Alaska in 2002–03 (cf. Pollnac and Poggie, 2006) indicated that in some fisheries in Alaska, the IFQ also led to a decrease in crew size (activity attributes) since there was no longer a need for a large crew to maximize catches in a short period, as there had been during the short pre-IFQ management fishing season. With the catch spread out over a longer period, the seasonal changes in the fishery[15] (activity attributes) were also influenced. Further, with a smaller crew the owner could rely on a few family members, reducing the need to hire nonfamily crew members (activity attribute), and in turn reducing the occupational mobility of those not coming from fishing families (social-community attributes, individual attributes). In addition, the cost of an IFQ became so large (activity attributes) that many young people lost the hope of ever accumulating enough capital to enter the fishery (individual attributes), hence restricting their occupational mobility (social-community attributes). Many former crewmembers were forced to leave the fishery (social-community attributes, social problems); some also lost hope of ever becoming a boat owner (individual attributes), hence impacting fishery employment level (social-community attributes, social problems). Relationships between these variables are shown in Figure 4, which illustrates the impacts of these changes in the occupation on other important variables including well-being.

The changed occupation structure of the impacted communities has resulted in greater social stratification, with relatively well-off IFQ holders (some holding multiple permits) gaining more power in the community and increasing their influence on management, at the expense of unemployed crew members and those who have been unable to accumulate multiple permits (social-community attributes, social problems). Thus, the well-being of the IFQ holders increased while that of the unemployed former crew decreased.

Fishermen forced out of the industry who have moved into other occupations, as well as those who see no chance to improve their position in the fishery, have decreased job satisfaction with its attendant negative impacts, including decreases in well-being. Those with IFQ's have increased job satisfaction (individual attributes) and well-being. Hence, well-being has improved for some and decreased for others (cf. Pollnac and Poggie, 2006). Loy (2006) reports on a similar situation developing in a new quota fishery for the Alaskan Bering Sea/Aleutians Islands king and Tanner crab fishery (*Paralithodes camtschaticus, P. platypus, Lithodes aequispinus, L. couesi, Chionoecetes bairdi, C. opilio, C. tanneri, and C. angulatus*), which has not only IFQ's but also individual processing quotas (IPQ's) for processors. Similar problems associated with IFQ's in other fisheries have been noted by Childers (2007). Discussion concerning measurement and analyses of these variables is found in the appendix.

Subsistence Fisheries

Subsistence fishing refers to fishing activity directed at capturing fish for consumption rather than sale. The simplest example would involve a person who captures fish for consumption by his or her nuclear household.[16] More complex examples involve capture and distribution networks of families with no sale involved. For example, Magdanz et al. (2002), conducting research in Wales and Deering, Alaska, using network analyses, identified eight production and distribution networks in Wales and six in Deering. Networks averaged 5 households (range 2 to 11) and 17 individuals (range 2 to 41).

Further, the simplest cases of subsistence fishing involve production of fish for human food, thus reducing the costs of feeding a family. Sometimes, however, the harvest is used to feed animals essential to subsistence activity. For example, in the Kotzebue District of Alaska, about 9% of the subsistence salmon harvest for 2003 was used to feed sled dogs, which was down from a high of between 29 and 34% in 1995–97 (Georgette et al., 2004).

In more complex but also relatively common cases, especially those involving distribution networks, the producers gain prestige and social security, rather than monetary income, by providing for networks of consumers (Kishigami, 2005; Stewart, 2005), and the act of sharing reinforces intra-group solidarity and cooperation so essential among subsistence peoples (Freeman, 2005; Stewart, 2005). The best producers harvest more than they and their immediate families need, and they share the excess with relatives and other people in the community, contributing to their relative prestige, and perhaps more importantly, to a sense of community and cooperation among the people of the community (Magdanz et al., 2002).

Finally, among some peoples, a subsistence-based lifestyle is an important aspect of cultural identification, and the product itself may form an essential part of specific cultural activities (Norris, 2002). Other than the preceding aspects of subsistence fishing, which are vastly more important in this sector than in commercial fishing (Fig. 2), many of the same issues identified for assessing the commercial fishery apply.

An example will help illustrate some of the relationships between the variables included in Figure 2 as well as the subsistence-specific variables discussed above relating to our model. The Makah Nation members in Washington, like many of the original inhabitants of the northwest coast of North America, have a long tradition of seal (*Callorhinus ursinus*, pre-1900; *Phoca vitulina* and *Zalaphus californianus* today[17]) hunting stretching for thousands of years into

[14]Derby fishing is a fishery of brief duration during which fishermen race to take as much catch as they can before the fishery closes. This typically leads to congested fishing grounds and unsafe fishing conditions, as well as lower quality fish and lower prices per pound.

[15]Annual round is another commonly used term for seasonal changes in fishing activity.

[16]In the context of subsistence fishing, "consumption" has two meanings. For some subsistence fishermen, fish provide food (i.e. nourishment in the form of protein and fats) for the body. For others, fish provide food (i.e. spiritual and ritual nourishment) for the soul. Both kinds of subsistence fishing are proper objects of SIA.

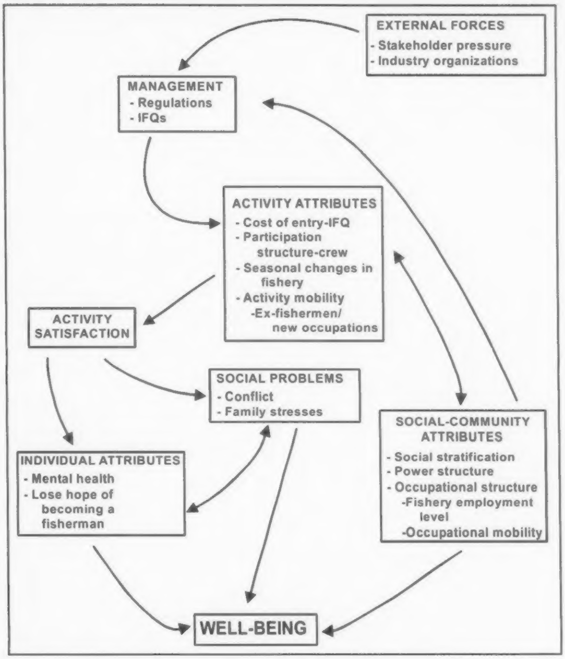

Figure 4.—Model of relationships between external factors, mediating variables, and well-being from the Alaska Pacific halibut and sablefish IFQ programs.

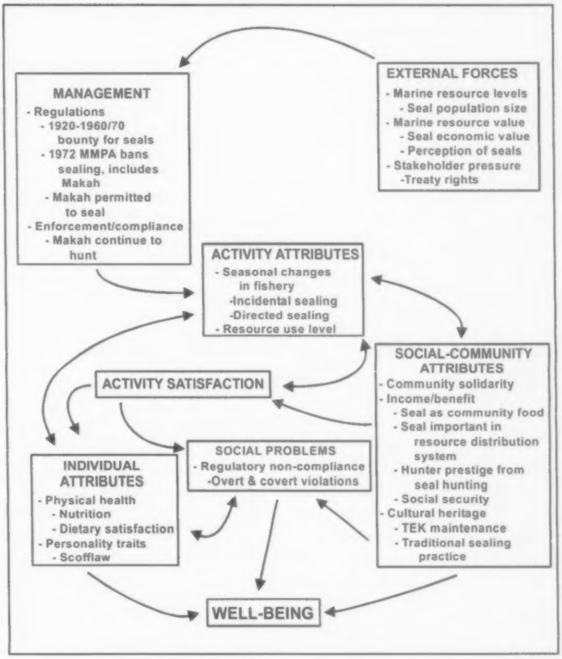

Figure 5.— Model of relationships between external factors, mediating variables, and well-being among the Makah Nation members.

the prehistoric past (Sepez, 2001).[18] Seal products formed a significant and desired part of the diet, and the hunting and distribution of these products were important elements in a communal distribution system, confirming social relationships and bestowing prestige on the hunters.

This tradition and its associated knowledge led the hunters to be hired as crew members on sealing schooners in the late 1860's, eventually purchasing their own boats and gear in the 1890's. This resulted in a high level of well-being for the Makah.

During the 1890's the United States began regulating sealing through international agreements, and seizures of Makah boats occurred despite the fact that the Treaty of Neah Bay gave the Makah the right to fish, whale, and seal in accustomed grounds, and Makah well-being declined.[19]

The Makah, contending that the treaty gave them the right to hunt, continued sealing, leading to further seizures. This resulted in a generalized distrust of both government resource management and commitment to treaty rights. This brief history provides the background to help explain the social impacts of interrelationships between efforts to manage seal populations and aspects of Makah society and culture in the 20th century. Figure 5 models the relationships discussed in the following example.

In the first part of the 20th century harbor seals were considered pests by society at large (i.e. not the Makah), in part due to their voracious consumption of other marine life (external forces). From the 1920's up until 1960 in Washington and 1970 in Oregon, bounty programs were implemented by the states (management), and Makah hunters could collect a bounty for each seal as well as keep seal products for consumption. Later perceptions of marine mammals as being in danger of extinction, as well as a developing belief in the larger society that these mammals are somehow special (external forces) led to the passage of the Marine Mammal Protection Act (MMPA) in 1972. This resulted in prohibiting the Makah from harvesting seals for any purpose, including the retention of incidental catch (management).

The Makah, believing that the Treaty of Neah Bay gave them the right to

[17]The Makah's seal hunting has usually encompassed several species at any given time. See J. Sepez, In press, Historical Ecology of Makah Subsistence Foraging Patterns, J. Ethnobio., and M. Etnier and J. Sepez, In press, Changing patterns of sea mammal exploitation among the Makah. *In* D. Papagianni, R. Layton, H. Maschner (Editors), Time and change: archaeological and anthropological perspectives on the long term in hunter-gatherer societies, Oxbow Books, Oxford, U.K., for a full discussion of historical and current Makah seal hunting.

[18]For specific references concerning aspects of Makah seal hunting discussed here consult Sepez (2001). We would like to thank the author for her willingness to discuss this section as it was being written and for reviewing the final product.

[19]The assessment of Makah relative well-being is made based on Sepez's (2001) research, and includes personal communication with her specific to this issue.

harvest seals for subsistence, continued to hunt (social problems) resulting in citations and confiscation of the seals (management). Due to these enforcement activities, sealing was reduced (activity attributes), denying hunters a pursuit they enjoyed (activity satisfaction) and one that provided them with food and prestige in the community (social-community attributes).

Seal products thus became scarce in the community distribution system, reducing an important contributor to social solidarity and social security (social-community attribute). The reduced availability of seal products in the community also negatively impacted nutrition and dietary satisfaction (individual attributes). Violations of the ban, however, continued (social problems), both covertly by changing sealing times and locations (activity attributes) and overtly, with seal being consumed at community parties (social problems). These continuing violations contributed to a scofflaw attitude regarding official U.S. Government management efforts (individual attribute, social problem).

Taken together, all these factors contributed to a decreased sense of both individual and social well-being. Reinterpretation of the MMPA in 1994 led to amendments, once again allowing Native American groups to harvest marine mammals as provided in their treaty rights, hence, beginning the process of reducing the negative impacts that occurred as a result of the original act.

Recreational Fisheries

We turn now to those who fish for other than commercial and subsistence reasons. For convenience, we employ recreational fishing as a cover term to denote leisure-based fishing which includes the most casual forms of fishing, the most serious forms of fishing by sportsmen, and also the "expense fishing" of those who fish for pleasure but sell their catch to cover some costs.

Recreational fishing takes place in a variety of settings. Variants on the recreational fishing theme include: 1) anglers fishing from their own boats, 2) anglers fishing from shore (e.g. on piers, beaches, riverbanks), 3) anglers who rent boats that they operate, 4) anglers who fish on charter boats (see glossary) with captains and crew, 5) anglers who fish on party boats (see glossary) with captains and crew, and 6) anglers who fish in tournaments and derbies.

As pointed out earlier, commercial and subsistence fishermen often congregate and reside in villages, communities, small towns, and neighborhoods. Although recreational fishermen do, at times, dwell in a particular geographic region, they are also very likely to be widely distributed. In many instances of fishery management, recreational fishermen are better regarded analytically as a community of interest than as a place-based community.

Recreational fishing has enormous value to participants and those who provide direct services and equipment, as well as local communities. While recreational fishing is frequently discussed in terms of its economic value, it also has important social and cultural values (Smith, 1980).[20] The sociocultural value of recreational fishing can be measured on multiple levels including relationships associated with the fishing trip itself and with the experience of fishing (e.g. with family or friends), with distribution of the catch, and with talking about fishing, i.e. "fish talk." There are also benefits to the individual such as fulfilling psychological needs like independence, risk taking, relaxation, and identity affirmation (Smith, 1980; Ditton et al., 1992; Fedler and Ditton, 1994; Ditton, 1996; Fedler, 2000; Ditton and Sutton, 2004).

To illustrate the kinds of analytical questions an SIA might address in the context of a recreational fishery, we draw upon events in southern California between 1998 and 2003 that resulted in the designation of a network of marine protected areas (MPA's) in the Channel Islands area. The simplified fishery SIA model (Fig. 2) is again our starting point, and the specific variables in the following example are illustrated in Figure 6. The Channel Islands of interest—which include the islands of San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara—lie off the California cities of Santa Barbara and Los Angeles.

The islands and the adjacent marine environment have long been valued for their considerable fishing resources and wildlife amenities. In 1980, Federal actions created the Channel Islands National Park and also the Channel Islands National Marine Sanctuary (CINMS).[21] The park boundary extends to 1 n.mi. off the islands; the sanctuary boundary extends to 6 n.mi. offshore (management).

Beginning in the late 1990's, a combination of special-interest-group initiatives (external forces), innovative state legislation, and natural resource management actions culminated in the creation of a network of MPA's (management) in California waters (NMPAC, 2003; Bernstein et al., 2004). In 1998, the California Fish and Game Commission (CFGC), which sets fishery policy for California state waters, received a recommendation from a group of citizens (including a very prominent recreational fisherman) who had formed the Channel Islands Marine Resources Restoration Committee to set aside 20% of a 1 n.mi. zone around the northern Channel Islands for no-take marine reserves (external forces).

In response to this request and in recognition of the need for a community process, CINMS and the California Department of Fish and Game (CDFG), which implements CFGC policies, developed a joint Federal/state partnership to examine MPA issues in the sanctuary.[22] In 1999, California enacted the Marine Life Protection Act (MLPA). This landmark legislation established a legal mandate for the creation of a system of MPA's (management).

[20]Driver (1983) provides a valuable master list of items and domains of experience for exploring recreation fishermen's preferences.

[21]Public Law 96-199 created the Channel Islands National Park. The Channel Islands National Marine Sanctuary was designated under the authority of the Marine Protection, Research and Sanctuaries Act of 1972. Pub.L. 92-532. See Fed. Regis., 45(193): 1980, Rules and Regulations, p. 65200.

[22]Discussion here is limited to Phase I (1999–2003) which concerned Channel Island National Marine Sanctuary waters under state jurisdiction. Phase II which concerns CINMS waters under Federal jurisdiction still continues.

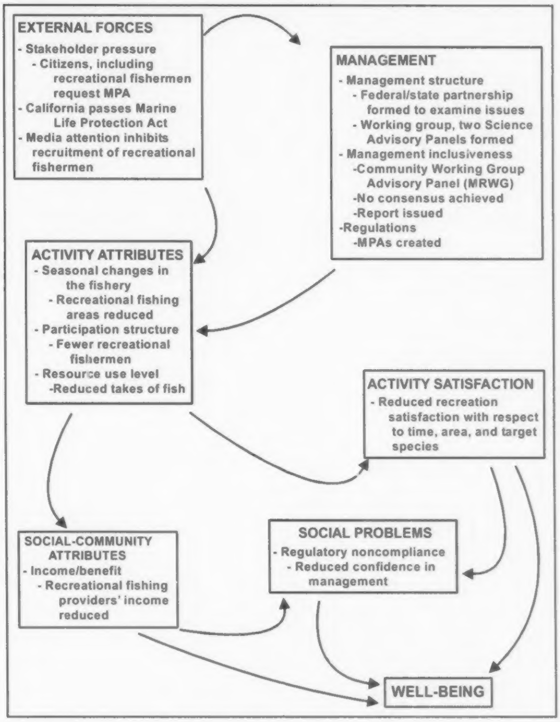

Figure 6.—Model of selected variables affecting the recreational fishery in the Channel Islands, Calif.

In 1999, the Sanctuary Advisory Council (SAC), an advisory group to the sanctuary manager, created a stakeholder-based community group called the Marine Reserves Working Group (MRWG). This group in turn created a Science Advisory Panel and a Socioeconomic Advisory Panel (management). In 2000, both panels recommended the creation of at least one reserve (but not more than four) comprising between 30 and 50% of the representative habitat in each area.

In reference to this recommendation, the socioeconomic panel (Davis, 2001, cited in NMPAC, 2003:31), estimated that a closure of 50% of the sanctuary would result in a maximum potential loss of about 50% in fishing industry revenue for both the commercial and recreational sectors (management). In 2001, MRWG reported to SAC that while members agreed on MPA goals, objectives, and issues (i.e. ecosystem biodiversity, socioeconomic issues, sustainable fisheries, natural and cultural heritage, and education) the group could not agree on one unified spatial recommendation. Importantly, two MRWG members representing recreational fishing constituencies sharply disagreed with recommendations from the Science Advisory Panel. In response, SAC forwarded all materials developed by MRWG and its two panels to the CINMS manager (management).

In 2001 CINMS and CDFG developed a preferred alternative based on the work of the MRWG and advisory panels and presented this to the CFGC (California Department of Fish and Game, 2006:64). In October 2002—and after extensive public review and discussion—the Commission approved the preferred alternative. This established a MPA network consisting of 1) ten (no-take) state marine reserves, 2) a state marine conservation area permitting limited recreational fishing off of Santa Cruz Island, and 3) another state marine conservation area permitting limited recreational and commercial fishing off of Anacapa Island. The total area protected with the system equaled 19% of the state waters within the sanctuary (Ugoretz, 2002:E-2; see also National Marine Protected Areas Center and NOAA Coastal Services Center, 2003:25–50). The state's MPA network went into effect 9 April 2003 (NOS, 2003:27990) (management).

The combined external forces and management actions discussed above have led to changes in areas where recreational fishermen may fish (activity attributes). One observer has argued that the substantial and prolonged media attention (external forces) to the creation of no-take reserves has inhibited the recruitment of recreational fishermen (Osborn, 2005:12) and also changed demand for recreational fishing providers (social-community attributes, activity attributes).

The potential loss of confidence in the fishery management regime among some recreational fishermen may precipitate social problems such as noncompliance. When all of the interactions of forces discussed above are taken into account, we believe that it is probable that the marine reserve process has negatively affected the activity satisfaction and well-being of some recreational fishermen, although this has not been directly assessed. At least on the perceptual level, some recreational fishermen may see the potential for their well-being to be reduced. Subsequent research can try to determine whether these perceptions are real. Relationships between all these variables are depicted in Figure 6.

Discussion

In this paper, we have introduced a general model for social impact assessment in the context of fishery management, especially as conducted by Federal and state executive agencies in the United States. Our model creates opportunities for social research tailored to examine (e.g. by correlation, by causality, via prediction and simulation) the

interplay of an array of social variables (e.g. individual and community attributes, social problems, job and other satisfactions, policy decisions), and their effect on community and individual well-being.

Although the model allows the analyst to study how these variables are related to one another, the most obvious overarching use of the model calls for the treatment of these social factors as independent variables that collectively influence the key dependent variable well-being. In elaborating on our model, we demonstrated that social impact assessment takes one of three analytical forms depending on whether the fishery in question is commercial, subsistence, or recreational.

This SIA model is heuristic and can be used to develop a truly quantitative model. Other researchers, in other contexts, have used all of the variables included in the model, and methods have been developed to quantitatively evaluate them at some level of measurement (nominal, ordinal, and interval). However, the variables have not been assessed together in terms of the model presented here. Ideally, some form of causal modeling should be used to test the heuristic model. Such a test would require obtaining data on included variables and testing the model using accepted methods (Blalock, 1964; Asher, 1983; Lieberson, 1985).

This could result in a predictive model that would allow one to change parameters in one part of the model and determine effects in the variable of interest (i.e. well-being). This process would also result in quantitative assessment of the relative importance of variables proposed for the model, perhaps resulting in some reduction in data needs. It is important to base assessments of the relative importance of different variables on quantitative evidence rather than unsubstantiated predictions.

We offer several recommendations regarding fishery applications of SIA. First, we believe this SIA model is useful as a foundation. Nonetheless, we stress that fishery SIA should not depend on any rigid obedience to one model, but it must continue to evolve methodologically in response to changing fishery realities.

Second, we must remember that fishery SIA is a requirement of Federal and other law to ensure that the best available science is provided to policymakers.[23] It is important to understand that SIA is a procedure to describe and predict the sociocultural impacts on selected human populations. It should not be used as a weapon to strategically manufacture "winners" in the policy arena. SIA conclusions are a specification of impacts and may be either negative or positive or both, and may be of major or minor significance. In the final analysis, SIA results are simply factors among others related to economic, biological, and habitat conditions to be considered by fishery managers in determinations of fishery management alternatives.

Third, we need to point out that the kind of SIA analysis outlined here requires data be compiled on many variables for which data are not now available (see appendix) at either the community, or, where appropriate, the individual level. Collection of these data requires NMFS to invest substantially in data collection and compilation and in new research. The recent expansion of the sociocultural analysis program began less than 5 years ago, and while its current funds have allowed it to begin compiling baseline information in each NMFS region[24], it will need substantially more funding and staff to collect the wider array of data required by this model. Good quality sociocultural analysis is no less expensive than good quality economic analysis or fish stock assessment.[25]

In conclusion, we note that SIA is a method that needs to grow in rigor and in its ability to evaluate relationships between variables. It is our expectation that with advances in social science theory and quantitative methodology, SIA will evolve in a manner that supports sound fisheries policy making and management. While commercial and recreational fishing will remain central foci of fisheries management, we envision a broader set of problems to which SIA in marine resource management and conservation is valuable. For example, increasing attention is being given to marine protected areas, open ocean aquaculture, ocean-based energy resources, and marine resource dependent tourism, such as whale watching. In the future, we foresee expanded application of SIA to these and other emergent marine resource management issues. The model presented here provides advice and recommendations that can also be applied to these issues.

Glossary

Activity satisfaction: The degree to which one's needs or wants are fulfilled in the conduct of a specific activity.

Charter boat: Any vessel-for-hire engaged in recreational fishing and hired for a charter fee by an individual or group of individuals (for the exclusive use of that individual or group of individuals), which results in that vessel being unavailable for hire to any other individual or group of individuals during the period of the charter (Blackhart et al., 2005).

Job satisfaction: See activity satisfaction—carrying out a job is a type of activity.

[23]In a recent article, Vanclay (2006) compares the principles of U.S. and international approaches to SIA, and concludes that the U.S. approach as described in ICPGSIA (2003), is "positivist/technocratic" in contrast to the "democratic, participatory, and constructivist" approach of the international SIA community (Vanclay, 2003). While the approach adopted by some in the international community has its attractions, social impact assessment work conducted for management actions by U.S. Federal agencies including fisheries must continue to use the best available science until such time as the relevant laws are changed to require something else.

[24]For examples, see the new Alaskan community profiles at http://www.afsc.noaa.gov/Quarterly/amj2004/amj04feat.pdf, accessed 11 July 2006, and the Gulf of Mexico Community profiles at http://sero.nmfs.noaa.gov/economics/economics.htm, accessed 11 July 2006. Similar profiles are nearing completions for other NMFS regions. Colburn et al. (2006) provides a more complete description of the developing program.

[25]Currently, U.S. Fishery Management Council administrative processes often include last minute changes in proposed regulations, thus restricting the ability of analysts to carry out ideal SIA's such as those implied by this conceptual model. Without changes to the regulatory process itself, it will remain difficult to meet the ideal.

Party boat (also called a head boat): Any vessel-for-hire engaged in recreational fishing and hired (or leased, in whole or part) for a per-capita fee on a first-come, first-served basis (Blackhart et al., 2005).

Perceived control: The degree that one feels that they have influence over events impacting some area of concern.

Resilience: The ability of a system to absorb perturbations by adapting to environmental changes (Berkes and Folke, 1998). With regard to humans, it can be defined as the degree to which an individual, family, or community can cope with change without becoming dysfunctional.

Self-esteem: The degree to which one has pride in or respect for oneself.

Social support system: The method by which a social institution such as the family, community, or some larger social group, provides assistance or encouragement to an individual or other social institution.

Well-being: The degree to which an individual, family, or larger social grouping (e.g. community) can be characterized as being healthy (sound and functional), happy, and prosperous.

Acknowledgments

The SIA Modeling Workshop was held at Belmont Conference Center, Elkridge, Md, 11–12 March 2004. Participants, in alphabetical order, included Susan Abbott-Jamieson (convener), James M. Acheson, Shankar Aswani, Patricia M. Clay, E. Paul Durrenberger, Peter Fricke, Henry P. Huntington, Jeffrey C. Johnson, Kathi Kitner, Marc L. Miller, Bryan Oles, Michael K. Orbach, Richard B. Pollnac, and Courtland L. Smith. The authors wish to thank Linda Putz for providing workshop facilitation and Rosemary Kosaka for providing workshop support.

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APPENDIX: Evaluation of SIA Variables

For marine resource SIA's, we recommend first constructing a table to facilitate systematic identification of both the units of analysis and the relevant variables for assessing impacts. Typically, units of analysis (e.g. individuals, firms, communities, tribes, regions) are the rows, while SIA variables are the columns.

Appendix Table 1 provides a comprehensive list of variables from which to choose those relevant for a particular SIA. It includes constructs, associated variables, and some measurement options for each. The long-term objective is to work toward agreement among marine social scientists on consistent operational definitions and standard, accepted measures for each. Consistent operationalization of SIA variables is necessary for making comparisons both across marine resource management SIA's and across time within a resource management SIA.

Some of the variables are in fact indices. Establishing defensible indices is difficult, but can be done by building an index based on work already completed. This appendix, the NOAA (1998, 2001) MSA National Standards and SIA operational guidelines, and historical examples (Pomeroy et al., 1997; Pollnac, 1998; Pollnac and Crawford, 2000; Berkes et al., 2001) all provide a basis for developing useful indices.[26] In all cases, the measures should enable global comparisons. What should be situation specific is the effort to explain the direction and magnitude of change in the index of well-being for particular individuals or groups of individuals at a particular point in time. Explaining why the index has risen or fallen or projecting future trends is the most useful outcome of SIA. The commercial, recreational, and subsistence examples provided in this article illustrate the system's approach and templates as applied to representative marine resource management problems.

Meta-Methodological Considerations

Levels of Measurement

Data should be obtained at the most precise level of measurement appropriate to the variable under consideration to facilitate statistical analyses. It is understood, however, that availability of information or funds to gather information may result in varying levels of precision. Hence, a useful database should accommodate different levels of measurement and provide descriptions of the methods used to facilitate appropriate interpretation of the data (Pollnac, 1998).

For example, the relative degree of solidarity in a community could be based on counts of cooperative organizations, churches, social organizations, and their membership. The total number of organizations, or total membership in such organizations, could be analyzed relative to the total population of a community. This value would be the most precise measure of relative solidarity across communities.

Alternatively, where such statistics are not available, the figure could be based on informant interviews where fishermen and other community members would be asked to list and rank the top five communities in terms of solidarity. Modal ranks for each community could be determined and used as a ranking of relative importance. In this case the level of measurement would be ordinal and not as precise as the previous measure. Nonetheless, it can be used in statistical analysis.

Sometimes information sources will use concepts such as low, medium, high, or some variant of these concepts to indicate a level of importance or use. Despite the fact that these are evaluative concepts, not numbers, they can be converted to numbers signifying an ordinal value. For example, the concepts none, low, medium, and high can be converted to the ordinal values 0, 1, 2, and 3, respectively.

It is extremely important that the direction (in terms of relative amount) of the ordinal values be known. For example, when ranking tasks are performed (e.g. ranking the relative levels of solidarity as in the example above), the top ranked community in terms of solidarity is usually given the rank of "number one" and the least important "number five," or whatever the total number ranked ends up to be. In terms of the direction of these numbers as related to the concept "importance" the numbers are the inverse (in terms of ordinal quantity reflected by 1, 2, 3, etc.) of the actual ordinal quantity.

Correlational analyses using ranks where one is "most important" can be potentially misleading since if this variable is entered into a correlation analysis with another variable where a higher number equals a higher level of the variable, the sign in the result will be negative when the correlation is in fact positive. Hence, in all cases in this database where the ordinal quantity of the concept being measured is higher than another ordinal quantity, the numeric value assigned will be higher.

[26]Other disciplines have constructed indices that are now commonly used. Economists constructed gross domestic product and unemployment as economic health measures. The index of consumer satisfaction is an economic bellwether, based on response to survey questions. Ecologists developed the Shannon-Weaver (1949) index of diversity (Krebs, 1989). Even temperature is a constructed index in which some societies use a Fahrenheit and in others a Celsius scale.

Finally, continuing with the relative solidarity example, in some cases the source of information may only indicate several communities as having a high degree of solidarity with no ranking. Here we have a simple dichotomy where a given community has solidarity or not—a simple yes/no, limited choice. This type of information is better than none at all, and it can also be used in statistical analysis; hence, accommodation will be made for it in the database. Therefore, each indicator, as appropriate, will have fields for different levels of measurement.

Perceptions

In the description of the variables, remember that there is often more than one measure of a given variable. We often move from actual observation using instruments or our senses, to official records, to triangulated key informant interviews, to individual perceptions. Ideally, the method used to evaluate perceptions of phenomena such as aspects of family and social problems, job satisfaction, level of community conflict, or ability to work together will be able to take advantage of the human ability to make graded ordinal evaluations.

For example, one has the ability to evaluate real world objects in terms of some attribute such as size and not only make the judgment that one is larger than the other, but also that one is a little larger, larger, much larger, or very much larger. Human behavior is based on graded ordinal judgments, not simply a dichotomous judgment of present or absent. For example, a person is more likely to take action if they perceive that an activity will benefit them "greatly" in contrast to "just a little." This refined level of measurement allows one to make more refined assessments concerning fisheries management impacts, as well as permitting use of more powerful statistical techniques to determine relationships between perceived impacts and potential predictor variables. There are several techniques that can be used to evaluate individual perceptions of the indicators we have identified.

One commonly used procedure for measuring degree of satisfaction or dissatisfaction is a Likert-type scale. In this procedure, the researcher asks the subjects to report how satisfied or dissatisfied they are with certain aspects of their occupation, community, or living conditions. If they respond "satisfied," they are then asked if they are "very satisfied," "satisfied," or "just a little satisfied." The same procedure is applied to a "dissatisfied" response.

Including the "neither" or neutral response, results in a 7-point scale, with 1 indicating very dissatisfied and 7 very satisfied. This is more an example of a semantic differential (Osgood et al., 1957). Respondents would be requested to make these judgments for two time periods: today and pre-implementation of the fishery management procedure. Clearly, this would be a cumbersome, time-consuming process with more than just a few indicators. Additionally, the technique might prove to be unreliable for uncovering minor changes between time periods due to the size of the categories used.

Another technique is a visual, self-anchoring, ladder-like scale, which allows for finer ordinal judgments, places fewer demands on informant memory, and can be administered more rapidly (Cantril, 1963). The subject is shown a ladder-like diagram with multiple steps, where the first step represents the worst possible situation.

For example, with respect to community harmony, the first step would indicate a community with a great deal of conflict, and where community members are involved in a great deal of verbal conflict over various issues such as school taxes, waterfront planning, immigrant populations, etc. The highest step would be described as a conflict free community in which town meetings are characterized by pleasant interaction, where consensus is easily achieved, no issues exist dividing the population, and peaceful interaction is normal.

In a fisheries application, the subject would then be asked where on a ladder (ruler, scale, whatever is appropriate for the subjects involved) the local area is today (the self-anchoring aspect of the scale). The subject would then be asked to indicate where it was before implementation of the fishery management procedure or some other earlier period to establish a baseline. The difference between the two time periods is the measure of change.

The two techniques described above do not provide the same information. The information is similar, but subject to slightly different interpretations. For example, a position on the self-anchoring scale does not necessarily indicate satisfaction or dissatisfaction, and we might be in error if we interpret a scale value above the mid-point as indicating individual satisfaction.

Likewise, satisfaction with an attribute (e.g. income) does not tell us where in the perceived range of income the individual places himself/herself. The self-anchoring scale, however, is both easier to administer and more sensitive to the changes we need to evaluate. For some applied examples see Pollnac and Crawford (2000).

While this discussion assumes that a sample of individuals will be interviewed, focus groups and/or scoping meetings are also commonly used. Social psychology researchers have demonstrated, however, that group responses are influenced by the most powerful or persuasive group members, distorting individual attitudes, beliefs, and values. Nevertheless, the same methods can be applied to a group for a consensus response.

It is suggested, however, that if the group is literate, they be given a printed questionnaire. In all cases, the responses will only reflect group or sample membership, which may not be representative of the target population. Local constraints sometimes require the SIA analyst to rely on opportunistic sampling, rather than on stratified random samples. Even in the opportunistic sampling situation, every attempt should be made to include members of all previously identified relevant populations.

Appendix Table 1.—SIA model variables.

Construct group	Constructs	Variables[1]	Suggested measurement strategies
External forces	1. Population pressure	Demographic statistics compared over time, population migration patterns	U.S. Census, comparing population figures over time for locations of interest; Federal government reports documenting changes in population patterns; state and local websites for locations of interest
	2. Stakeholder pressure	No. of environmental NGO-generated lawsuits; no. of news media articles discussing related public pressure; no. of related organized meetings, other events; no. business associations expressing interest; treaty rights	Develop an index of pressure from publicly available information including no. of NGO-generated lawsuits, content analysis of relevant NGO websites, content analysis of news media, and other relevant archival resources
	3. Marine resource levels	Fish stock levels; sea mammal population levels; other marine resources	Specific species or species complex; state and/or Federal fish stock assessments for regions of interest; Federal and state sea mammal population estimates; Federal/state estimates other marine resource levels
	4. Marine resource value	Price; non-market value	NMFS Market News; various governmental and non-governmental price and market surveys; sample survey; archival resources
Management	5. Management structure	Complexity of management	1) Sample survey of perceptions of complexity of the management structure; 2) index including, for example, number of gears managed per year, number of species managed per year, number of management measures introduced per year; number of governance bodies involved; 3) count of jurisdictional entities
	6. Regulations	Fairness, complexity, restrictiveness, and effectiveness of regulations	1) Sample survey of perceptions, 2) archival sources (e.g. news media, lawsuits, NGO, and other scorecards)
	7. Management inclusiveness	Public involvement in management processes	1) Sample survey of perceptions, 2) archives or observations: counts of public comments in documents and number/type of participants at public meetings
	8. Enforcement and compliance	Levels/types of enforcement and noncompliance with activity regulations, whether formal or informal	1) Sample survey/structured interviews/triangulated key informant interviews of individual reports and/or perceptions (including questions about behaviors of others), 2) archival data (e.g. review fisheries law enforcement reports and news media; numbers of citations and infractions, normalized for nonuniform levels of enforcement coverage; creel survey reports)
Activity attributes	9. Annual rounds	Structure of annual round	Sample survey/key informant interviews regarding activity types (marine and non-marine) by month and location. Locations of activities should be mapped, using place names and results of mapping exercises—translated to GIS
	10. Fishing units/gear types	Vessel/gear type combinations	Sample survey; open-ended/structured interviews/pile sorting/consensus analysis; observation-based empirical methods; agency effort and permit data; official license/port/harbor data, if available; observation to ground truth other methods. If conflicting data from various sources, a census may be necessary. Fishing gear taxonomies have been developed by states, interstate commissions, and Federal fisheries managers and vary by region and source.
	11. Fishing method/mode	Method/mode combinations of fishing: 1) shore-based, including man-made and natural structures (e.g. beach, pier, jetty, bridge); 2) party/charter boat; 3) private/rental boat; 4) commercial vessel	Sample survey; open-ended/structured interviews/pile sorting/consensus analysis; observation-based empirical methods; MRFSS; official permit/license/port/harbor data, if available; observation to ground truth other methods. If conflicting data from various sources, a census may be necessary
	12. Resource use level	Harvest level or activity intensity (including avidity), perceptions of abundance. Where feasible identify by mode (i.e. commercial, recreational, or subsistence)	1) Sample survey, open-ended and structured interviews, 2) NMFS landings data, state landings data, subsistence databases, MRFSS, counts of infrastructure, DAS, CPUE, vessel counts, license and permit data, other relevant databases
	13. Resource use patterns	Distribution, processing, and consumption patterns; social networks (including references to reciprocity and other commercial and noncommercial forms of exchange); marketing chains (including references to vertical and horizontal integration)	1) Sample surveys; network analysis; in-depth interviews; triangulated key informant interviews, 2) archival, public information on marketing chains
	14. Cost of entry	For each vessel/gear type combination obtain costs of new and used vessels/gear, license and other fees (e.g. dock fees), and cost of property/access rights; trip expenses (e.g. cost breakdown of transportation, bait, gear, ice, lodging, food, fees); training time expenses; insurance, financing	1) Triangulated key informant interviews (fishermen, vessel/gear salespersons), surveys, in-depth interviews, 2) archives or observations: classified advertisements, party/charter fees, marina slip expense, rental boat fees, launch/ramp fees, license fees, pier fees, lodging costs, etc. Some elements of cost of entry captured in agency economic data collections

continued

Appendix Table 1.—(continued) SIA model variables.

Construct group	Constructs	Variables[1]	Suggested measurement strategies
	15. Ownership patterns	Individual owner demographic profiles, including age, sex, residency, income, education, total years participating in activity; corporate owned vessels, include years in business, number of vessels owned, a rating or ranking measure of size of business using gross income or proxy measure as possible, location of incorporation of business and principal place of business, number of employees	1) Sample survey/triangulated key informant interviews; 2) public statistics; 3) Coast Guard vessel registry data; 4) state vessel registry data; 5) Federal and state permits databases; 6) Dunn & Bradstreet business registry; state business registries
	16. Participation structure	For each activity type obtain information about participants, including number; positions/roles (e.g. owner captain, captain, engineer, cook, deckhand, shell shucking, ritual specialist) as appropriate; participant hierarchy; general participant selection criteria (e.g. kinsmen if available, friends, levels of skill); and participant demographic information (including residence)	1) Sample survey/triangulated key informant interviews including SSN (can't require it) or crew ID number (only Alaska has crew licenses), vessel ID currently employed, location of owned vessel/plant currently employed in (and plant ID no.), individual or corporate ownership, current ports of landing, 2) licenses and other databases
	17. Safety	Level of safety of the activity	1) Sample survey/individual reports on perceived safety/likelihood of risk-taking behavior, 2) Coast Guard records (CASMAIN files), state records, harbormaster records normalized for level of enforcement coverage
	18. Physical resources/ infrastructure	Condition and adequacy of activity-related physical resources/infrastructure	1) Sample survey of perceptions; triangulated key informant interviews (including Chamber of Commerce members, fishermen, harbormaster, etc.); 2) number of docks, cold stores, distribution and marketing facilities, gear and vessel supply and maintenance facilities, marinas, marine repair, marine supply, party/charter boat operations, boat rentals, bait and tackle shops, marine electronics shops, boatyards, boat lifts, boat storage, boat sales, pay piers, ramps and associated infrastructure, public access sites, fishing clubs and associations, dockside motels/lodging, number of hospitals and other health care facilities, airports, marine ports, factories by industry, major roads, etc.; archival research on comprehensive plans and economic studies of angling in the community
	19. Activity mobility	Mobility within an activity; alternative activities (including jobs, recreation, and subsistence); and substitutability	1) Sample surveys/interviews/triangulated key informant interviews/free listing/pile sorting (including current and former activity participants) on perceived/preferred/potential alternate activities, existing activity structure, activity participants' education and training, social/political capital, physical capital, social stratification, power structure; 2) counts and archival data on available industries/jobs, available formal and informal training and retraining programs and their participation rates, etc.
Activity satisfaction	20. Activity satisfaction	Level of satisfaction derived from or associated with participation in the activity	Sample survey/individual reports including aesthetics, perceived quality/health of the resource, job satisfaction, trip satisfaction, desire to continue participating, desire for children and grandchildren to continue participating, recent vessel and/or equipment purchase
Individual attributes	21. Participant characteristics	Participant demographic profiles, including age, sex, residency, income, education, total years participating in activity	1) Sample survey/triangulated key informant interviews, 2) public statistics, 3) crew licensing data where available
	22. Mental health, individual	Mental health condition of individuals	Sample survey/self report instruments on stress-related disorders and treatment (e.g. depression, stress, drinking, psychosomatic illnesses, anxiety, self-esteem issues, psychiatric care, and counseling)
	23. Physical health, individual	Physical health condition of individuals	Sample survey/individual report instruments of physical health (including heart disease, injuries, diet/nutrition deficiencies/adequacy, especially for subsistence, etc.)
	24. Resilience, individual	Capability of individuals to cope successfully in the face of significant adversity or risk	Sample survey including work history and training, religiosity, self esteem, available support systems, perceived levels of stress, perceived ability to cope, sources of income, level of education, etc.; key informant interviews
	25. Personality traits	Distinctive behavioral regularities across diverse life situations through time	Sample survey using standardized self-report personality trait assessment instruments; relevant questions from Driver[2], master list of items for recreational experience preference scales and domains; interviews.
Social-community attributes	26. Demographic characteristics	Demographic statistics for place-based and activity-based communities	1) Sample survey of residence patterns, location of activities in relation to residence; 2) U.S. Census, Bureau of Labor Statistics, community strategic plans including total population, sex, age, race, ethnicity, origins and language, housing, owner/renter status, education, employment, housing tenure, housing mortgage status, religious affilia-

continued

Appendix Table 1.—(continued) SIA model variables.

Construct group	Constructs	Variables[1]	Suggested measurement strategies
			tion; official license/port/harbor data over time, if available; license plate counts from public launches and dock parking lots; licensing databases and other archival data
	27. Social stratification	Type and degree of social stratification and differences in place-based and activity communities	1) Sample survey on perceptions/self-reports including income; education; access to social/physical capital and resources; triangulated key informant interviews; 2) construct gini-coefficient (or coefficient of variation, quartile measures) for a) distribution of property values (from tax assessment records, if available, and if not, a visual survey of houses/property), b) distribution of income based on estimates for different jobs as associated with data from occupation structure of the community, c) census data on educational and income levels, d) archival data on zoning/land use patterns and plans, including comprehensive community planning documents
	28. Power structure	People, public and private organizations and institutions who have influence or authority within the place-based and activity communities	1) Sample survey of perceptions; triangulated key informant interviews and network analyses re. informal power structure, 2) archival data on formal power structure (e.g. news media, official town documents); observational studies (informal power structure)
	29. Occupational structure	Occupational structure of place-based and activity communities	1) Sample survey of employment history (e.g. occupations held, reasons for entry and exit, levels of remuneration); triangulated key informant interviews; 2) employment by sector and subsector from town records, Chamber of Commerce, local office of employment security, official license/port/harbor data
	30. Income/benefit	Proportion of income from activity, and/or proportion of activity-related product in diet (Note: Benefit in this context is defined as subsistence use of activity-related products.)	1) Sample survey of households on income, employment and other benefits (e.g. role of activity in diet and nonmonetary transfers) from the activity; 2) gross community product by sector and subsector from tax data, utilities, gross receipts, etc.; 3) use of resource in prestige rankings, establishing and reinforcing familial/extra familial social networks; 4) use of resource in redistribution systems
	31. Dependence	Level of dependence of place-based community, households and families on the activity [Note: A current working NMFS definition is: Dependence is a measure of the level of participation in a fishery relative to other community activities, and relative to all other communities linked to fishing in some way (Norman et al.[3])].	Archival data, databases (see indicators listed in Norman et al.[3])
	32. Engagement	Level of engagement of place-based community, households and families on the activity [Note: A current working NMFS definition is: Engagement is a measure of the level of participation relative to the overall level of participation in a fishery (Norman et al.[3])]	Archival data, databases (see indicators listed in Norman et al.[3]).
	33. Community solidarity	Levels of solidarity in place-based and activity communities	1) Sample survey (including questions on strength of networks, sociopolitical voice, cultural homogeneity/heterogeneity, kinship ties, connectivity between migrants, definition and sense of community, social capital, participation in expressive culture including events such as blessing of the fleet and fishing tournaments); network analysis; 2) number of cooperative organizations, churches, social organizations, etc. and their membership; network density (connectivity measure), observed participation in expressive culture including events such as blessing of the fleet and fishing tournaments; public presence of material culture such as sculptures, pictures, or other memorabilia celebrating the community
	34. Physical health-community	Physical health condition of place-based and activity communities	Community physical health survey; prevalence and incidence rates from public health records (local, county, state, CDC) on infant deaths, number childhood immunizations, health of workforce, etc.
	35. Mental health-community	Mental health condition of place-based and activity communities	Prevalence and incidence rates from public health records (e.g. state, county, local databases, CDC) of stress-related disorders and treatment (e.g. depression, stress, drinking, psychosomatic illnesses, anxiety, self-esteem issues, psychiatric care and counseling); sample surveys on community mental health; triangulated key interviews with local healthcare professionals
	36. Cultural heritage and norms/values	The role of activity and marine environment in history, spirituality, self-representation/identity, and knowledge production	1) Sample surveys including perception of activity importance to community, beliefs about marine ecosystems, atti-

continued

Appendix Table 1.—(continued) SIA model variables.

Construct group	Constructs	Variables[1]	Suggested measurement strategies
			tudes toward marine ecosystems, environmental attitudes, cultural importance of marine ecosystems; triangulated key informant interviews on traditional ecological knowledge and local activity knowledge (e.g. local fisheries knowledge) and religious/spiritual beliefs/institutions; 2) archival data (e.g. newspapers, Chamber of Commerce information, environmental historical documents, iconography)
	37. Resilience-community	Capability of coping successfully (resilience) in face of significant adversity or risk in place-based and activity-based communities, families, and households	1) Place-based community index based on items such as job diversity; distance to county seat; distance to state highway; distance to interstate highway; distance to regional center for retail shopping, medical care, and financial services; cultural commonality/ethnic homogeneity; number of associations and organizations; number of members in associations and organizations; perceptions of leadership quality/proactive orientation; community attractiveness; evidence of past adaptations to nonlocal change affecting community; 2) activity-based community index based on items such as no. of activity-related businesses, support industries and associations; no. of members in associations; level of recruitment of activity participants; trends in activity-related resource levels and regulations/restrictions on access to these resources; cost of entry; no. of permits per vessel for commercial fishing
Social problems	38. Social problems	Social problems in place-based and activity communities and families	1) Sample survey/structured interviews/triangulated key informant interviews (including social workers, police, etc.); 2) public statistics (local, county, state, CDC) including spouse abuse incidents, crime incidents, alcohol abuse counts, drug abuse counts, poverty rate, number of children on reduced price lunches at schools, literacy, oral fluency in English, unemployment rates; archival data from local newspapers
	39. Conflict	Level of conflict in place-based and activity communities (both within and between groups) and in families	1) Sample surveys/structured interviews/triangulated key informant interviews, 2) police reports, news media, court cases filed, agendas from town board meetings
	40. Regulatory non-compliance	Levels/types of noncompliance with activity regulations, whether formal or informal, in place-based and activity communities	1) Sample survey/structured interviews/triangulated key informant interviews of individual reports and/or perceptions (including questions about behaviors of others); 2) archival data (e.g. review fisheries law enforcement reports and news media; numbers of citations and infractions, normalized for non-uniform levels of enforcement coverage; creel survey reports)
Well-being attributes	41. Index of well-being	Levels of well-being in place-based and activity based communities, families, and individuals	1) Sample survey of perceptions/self-reports including a) happiness (individual, familial, and communal), b) empowerment, c) self-esteem, d) satisfaction with aspects of living conditions, e) satisfaction with relationships (familial, communal), etc.; 2) Quantitative indicators of the change in objectively measured well-being index (e.g. Human Development Index, Index of Social Well-being, Canadian Well-Being Index, Oregon Progress Indicators) and/or distributions for variables such as community, family, or individual living conditions, stature, wealth, or power

[1] Get temporal comparative data 1980 to present where possible.

[2] Driver, B. L. 1983. Master list of items for recreation experience preference scales and domains. USDA For. Serv. Rocky Mt. For. And Range Exp. Sta., Ft. Collins, Colo. Unpubl. Doc., 10 p. Online at http://wilderdom.com/html/DriverREPScales.doc, accessed 1 May 2007.

[3] Norman, K. , J. Sepez, H. Lazarus, N. Milne, C. Package, S. Russell, K. Grant, R. Petersen, J. Primo, E. Springer, M. Styles, B. Tilt, and I. Vaccaro. 2006. Community profiles for West Coast and North Pacific fisheries—Washington, Oregon, California, and other U.S. states. NMFS-NWFSC, NOAA, 625 p. Online at http://www.nwfsc.noaa.gov/research/divisions/sd/communityprofiles/Supplemental_Community_Profiling_Document_DRAFT.pdf, accessed 6 May 2007.

Length-weight Relationships of Dolphinfish, *Coryphaena hippurus*, and Wahoo, *Acanthocybium solandri*: Seasonal Effects of Spawning and Possible Migration in the Central North Pacific

JAMES H. UCHIYAMA and CHRISTOFER H. BOGGS

Introduction

In the Hawaii commercial longline, troll, and handline fisheries for highly migratory pelagic species, both dolphinfish (mahimahi), *Coryphaena hippurus*, and wahoo (ono), *Acanthocybium solandri*, are incidentally caught and are of secondary importance to tunas, Scombridae, and billfishes, Istiophoridae. Their relative abundance, market demand, and relatively smaller size contribute to their secondary role. However, as people became more health conscious in the late 1970's, coupled with the decline of many fisheries, the demand for both dolphinfish and wahoo increased.[1] In 2003, the last year for which complete Hawaii state fishery landings were compiled, 596 t of dolphinfish and 446 t of wahoo were landed by the commercial fishery in Hawaii.[2]

As the focus of fishery management broadens to include a wider range of species in marine ecosystems, a growing need exists to evaluate catch data on species caught incidentally. Weight-on-length (W-L) and length-on-weight (L-W) relationships are needed to convert at-sea length measurements to weights, market weight data to length, and to examine patterns in fish condition that may provide insights into reproductive life history and ecology.

Many W-L predictors have been published for dolphinfish; these relationships have been described from the Mediterranean Sea (Bannister, 1976; Massuti et al., 1999); eastern tropical Atlantic (Castro et al., 1999), western tropical Atlantic and the Caribean (Oxenford and Hunte, 1986b; Oxenford, 1999), the Straits of Florida (Beardsley, 1967), Gulf of Mexico and the Gulf Stream (Gibbs and Collette, 1959), and North Carolina waters (Schuck, 1951; Rose and Hassler, 1968). In the Pacific, W-L predictors have been described for dolphinfish caught off Colombia and Panama (Lasso and Zapata, 1999), the entire Pacific Ocean (Takahashi and Mori, 1973); Hawaii (Tester and Nakamura, 1957); and Taiwan in the western Pacific (Wang, 1979). In the Indian Ocean, Chatterji and Ansari (1985) examined sexual dimorphism in W-L relationships for east African dolphinfish. Hence, most of these studies examined fish in populations distant from Hawaii. The lone Hawaiian study—fish caught off Kaneohe Bay, Oahu—was based on a relatively small number of measurements for mostly juvenile fish (Tester and Nakamura, 1957), and it is inadequate for describing the full size range of dolphinfish that is commercially landed in Hawaii.

Where many W-L predictors for dolphinfish have been described globally, only three published reports (Iversen and Yoshida, 1957; Beardsley and

[1]Takenaka, B., L. Torricer, J. C. Cooper, and S. C. Pooley. 1984. Trends in the market for mahimahi and ono in Hawaii. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-84-9, 19 p.

[2]Hamm, D. C., N. T. S. Chan, and C. J. Graham. 2005. Fishery statistics of the western Pacific, Vol. 20. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Pac. Isl. Fish. Sci. Cent. Admin. Rep. H-05-1, 196 p.

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ABSTRACT—Weight-on-length (W-L) relationships for 2,482 dolphinfish, Coryphaena hippurus, *and 1,161 wahoo,* Acanthocybium solandri, *were examined. Data on fork length, whole (round) weight, and sex were collected for dolphinfish at the Honolulu fish auction from March 1988 through November 1989. Unsexed weight and length data for wahoo were collected at the auction from July 1988 through November 1989. We also used sex specific weight and length data of 171 wahoo collected during 1977–1985 research cruises for analysis. Coefficients of W-L regressions were significantly different between the sexes for dolphinfish. Coefficients did not significantly differ between the sexes for wahoo based on research cruise data. In a general linear model evaluating month as a categorical factor, month was significant for female dolphinfish, male dolphinfish, and wahoo with sexes pooled. W-L and length-on-weight (L-W) relationships were fitted by nonlinear regression for all dolphinfish, female dolphinfish, male dolphinfish, and all wahoo sexes pooled. W-L relationships for monthly samples of female dolphinfish, male dolphinfish, and all wahoo with sexes pooled were also fitted by nonlinear regression. Predicted mean weight at length for wahoo was highest at the beginning of the spawning season in June and lowest after the spawning season in September. Maximum and minimum predicted mean weight at length for both sexes of dolphinfish did not correspond with the peak spawning period (March–May). Plausible migration models in conjunction with reproductive behavior were examined to explain the variability in monthly predicted mean weight at length for dolphinfish.*

Richards, 1970; Santana, et al.[3]) and a PhD. thesis (Hogart, 1976) have described W-L relationships for wahoo. A recently published review on wahoo from the western Central Atlantic region by Oxenford et al. (2003) mentioned three other studies in a table of various morphometric relationships. Beardsley and Richards (1970) provided a W-L relationship for wahoo from southeast Florida using data obtained from taxidermists. Hogarth (1976) described a W-L relationship for wahoo based on data from the sport fishery off the North Carolina coast. Santana et al.[3] described the W-L relationship of wahoo caught around the Canary Islands in the eastern Atlantic Ocean. In the Pacific Ocean, Iverson and Yoshida (1957) provided a W-L relationship for wahoo caught around the Line Islands in the equatorial central Pacific. There has not yet been a thorough evaluation on the W-L relationship for wahoo caught around the Hawaiian Islands.

Highly migratory management species (tunas, billfishes, dolphinfish, wahoo, and other incidentally caught species) are caught by the local fisheries around Hawaii and sold at the local fish auction. The Hawaii-based longline fishery has provided the majority of the dolphinfish and wahoo landed at the fish auction, but the troll fishery, bait boats, and the handline fishery (i.e. deep-sea handline, ikashibi, and palu-ahi) also have contributed significantly to total landings (NMFS, 2001). Wahoo landings peak in weight in May and are lowest in December–January. Dolphinfish landings peak in weight in the spring and again in the fall.[2]

Both dolphinfish and wahoo belong to the species complex of Pelagic Management Unit Species for the Western Pacific Regional Fishery Management Council (NMFS, 2001), where they represent an important component of the commercial landings. Stock assessment analyses and ecosystem models can be improved with more accurate morphometric relationships. Weight-length relationships are also useful for converting metrics in tag and recapture experiments and in databases lacking either metric, and they can be used to indicate body condition or robustness of fish in a stock (Le Cren, 1951). This study on dolphinfish and wahoo landed at the Honolulu fish auction during 1988–89 describes W-L predictor variables based on a large number of measurements covering a wide size range. The effects of sex and month on the variables were also examined.

Material and Methods

Dolphinfish morphometric data[4] were collected at the United Fishing Agency[5], Honolulu's public fish auction, from March 1988 through November 1989, except for December 1988 and June 1989. Wahoo morphometrics[4] were collected from July 1988 through November 1989, except for December 1988 and June 1989. Prior to the opening of the auction, fork-lengths (FL) of dolphinfish and wahoo were measured to the nearest millimeter using a meter-long fish caliper, and corresponding whole weights (W) were estimated using the auction scale.[6] When fish length exceeded 1 m, a mark was scratched on the skin at 1 m and the remainder of the fish length was measured to complete the measurement. Weights were recorded to the nearest 0.5 lb at the auction and later converted to kilograms. Small dolphinfish and wahoo were frequently sold in lots of 2–6 fish with a combined weight. These fish did not have individual weights and were not used in these analyses. The sex of dolphinfish was based on the pronounced forehead crest that is present in sexually maturing or mature male dolphinfish but absent from females (Fischer and Whitehead, 1974).

Data were first checked for outliers. All weight-length data for a species were first fitted to a (natural) log linear W-L regression, and outliers greater than ± 3 Studentized residuals were eliminated from the data file as it was believed that these were measurement or recording errors. Then sexual dimorphism and monthly effects were examined by comparing the slopes and intercepts by multiple regression analysis for the sexes or by a general linear model (GLM) for month of landing. The GLM was a type III sum of squares for unbalanced design analysis which included a battery of linear regression related analyses.

To determine the statistical significance of sex and month effects, data were trimmed so that each category contained data for a similar range of fish lengths, an ANCOVA requirement. Fewer data were removed for testing sex effects than for testing month effects, because of the larger length range for each sex pooled over all months. Less overlap was available among months. To preserve sample size, the monthly data were not trimmed as strictly, and, after trimming, not all months completely overlapped. If no difference in W-L relationships was found between sexes, female and male W-L data were pooled by month.

Sex information for wahoo was unobtainable at the auction, so data collected on Northwest Hawaiian Island research surveys from 1977 to 1985 were used to examine the effect of sex on the W-L coefficients. These cruises were conducted on the NOAA ship *Townsend Cromwell*, where FL of wahoo was measured to the nearest millimeter using a meter long fish caliper; W was obtained using a Maco 25 platform scale[5] to the nearest dekagram (10 g); and sex was determined by macroscopic examination of the gonad.

Once the statistical tests on trimmed data were completed, relationships were fit to the untrimmed data to provide the best empirical description for each sex or month. Log-linearized W-L regressions of dolphinfish and wahoo were calculated so parameters and other statistical data would be available for comparison with W-L relationships

[3]Santana, J. C., A. Delgado de Molina, and J. Ariz. 1993. Estimacion de una ecuacion talla-peso para *Acanthocybium solandri* (Cuvier, 1832) capturado en la Isla de el Hierro (Islas Canarias). Int. Comm. Conserv. Atl. Tunas (Madrid), Collect. Vol. Sci. Pap. 40(2):401–405.

[4]U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Pac. Isl. Fish. Sci. Cent. DATA SET RI016.

[5]The National Marine Fisheries Service, NOAA, does not approve, recommend, or endorse any proprietary products or proprietary material mentioned in this report.

[6]Scales at the auction are checked annually by the Measurement Standards Branch of the Department of Agriculture, State of Hawaii.

determined by the same method for fish caught in other areas. W-L and L-W relationships without log transformation were solved by seeking a least squares solution to the nonlinear equations:

$$W = a(L^b) \text{ and } L = a(W^b),$$

where W is whole weight (kg), L is fork length (cm), and two fitted parameters, a as coefficient and b as exponent. Nonlinear equations were preferred as more accurate and more convenient to use. Monthly changes in condition (weight at length) were illustrated by estimating predicted weights for three or four reference lengths and plotting the predicted weights with their standard error estimates. Statistical analyses were performed with Statgraphics Plus (Manugistics, 2000).

Table 1.—Multiple regression analysis evaluating the effect of sex on log-linearized whole weight-on-fork length (range 65–137 cm) relationships for central North Pacific dolphinfish landed at the Honolulu fish auction.

Parameter	Estimate	se	t test	p-value
Coefficient for males	–12.201	0.122	–99.46	<0.01
Exponent for males	3.111	0.025	120.06	<0.01
Difference in coefficient for females	0.689	0.158	4.34	<0.01
Difference in exponent for females	–0.168	0.033	–4.99	<0.01

$r^2 = 0.93$
$n = 2448$
Durbin-Watson statistics = 1.994, p = 0.44

Table 2.—Summary of generalized linear model type III sum of squares analysis evaluating the effect of month (of landing) on log-linearized whole weight-on- fork length (FL, range 90–135 cm) relationship for female central North Pacific dolphinfish.

Source	Sum of squares	df	Mean square	F-ratio	p-value
log-FL	31.895	1	31.895	3874.98	<0.01
Month	0.153	10	0.015	1.87	<0.05
Month*log-FL	0.154	10	0.015	1.88	<0.05
Residual	10.914	1,326	0.008		
Total	84.617	1,347			

Table 3.—Final reduced model of generalized linear model type III sum of squares analysis evaluating the effect of month (of landing) on log-linearized whole weight-on-fork length (FL, range 90–135 cm) relationship for male central North Pacific dolphinfish.

Source	Sum of squares	df	Mean square	F-ratio	p-value
log-FL	77.571	1	77.571	9350.59	<0.01
Month	0.736	10	0.073	8.88	<0.01
Residual	7.391	891	0.008		
Total	95.141	902			

Results

Dolphinfish

Male dolphinfish achieve larger sizes than females. The largest male during the sampling period measured 149 cm, whereas the largest female measured 137 cm. In the initial data examination consisting of 2,495 paired measurements, 13 observations were identified as outliers and deleted from all further analyses. Using data trimmed to a range of 65–137 cm FL, the differences in W-L parameters based on sex for dolphinfish were both significant (coefficient: p <0.01 and exponent: p <0.01; Table 1). Females and males were separately grouped by month of landing; data were trimmed to only include fish in the 90–135 cm FL range, and then analyzed by GLM. Other than March and April, most months covered about 90% or more of the trimmed length range. Month as a categorical factor was significant for both females ($p < 0.05$; Table 2) and males ($p < 0.01$; Table 3).

After completing hypothesis testing for dolpinfish, remaining analyses used the untrimmed data. Nonlinear W-L and L-W relationships were fitted for female and male dolphinfish (Fig. 1–4; Table 4), and a L-W relationship with sexes pooled is provided for applications where sex is unavailable (Fig. 5; Table 4). Log-linearized W-L relationships for females and males were also fitted for comparison with published studies that used this model (Table 4). Nonlinear W-L relationships were calculated separately for females and males for each of the 11-month groups using the untrimmed data (Tables 5 and 6).

To examine changes of condition or weight at length over time, monthly mean predicted weights with their standard error estimates were plotted for females at reference lengths of 80 cm, 100 cm, 115 cm, and 125 cm; and for males at reference lengths of 105 cm, 120 cm, and 135 cm FL (Fig. 6, 7, respectively). Reference lengths for male dolphinfish were three equally spaced lengths in the observed monthly length range. Reference lengths for female dolphinfish were selected where specimens were adequately present in monthly samples. Only in April (88 cm FL) and July (83 cm FL) were weights for females at 80 cm FL predicted beyond the minimum observed length for the month. The condition of dolphinfish was lowest in February or March and highest in September or October for both sexes and all reference sizes. The maximum differences in monthly predicted mean weights for females were 14.9% at 80 cm FL; 9.7% at 100 cm FL; 6.5% at 115 cm FL; and 7.8% at 125 cm FL for females. Among males, the maximum differences in monthly predicted mean weights were 12.5% at 105 cm FL; 10.6% at 120 cm FL; and 10.5% at 135 cm FL. There was also some evidence of increased condition in April and May, and decreased condition some time in the summer. The data are somewhat suggestive of two oscillations per year, peaking in October and in April–May and declining in summer and in November.

Wahoo

Since the sex of wahoo was unobtainable at the fish auction, length-weight-sex data collected on research cruises were used to examine sexual dimorphism. Female wahoo measurements ranged from 84.5 to 157.5 cm FL (n =

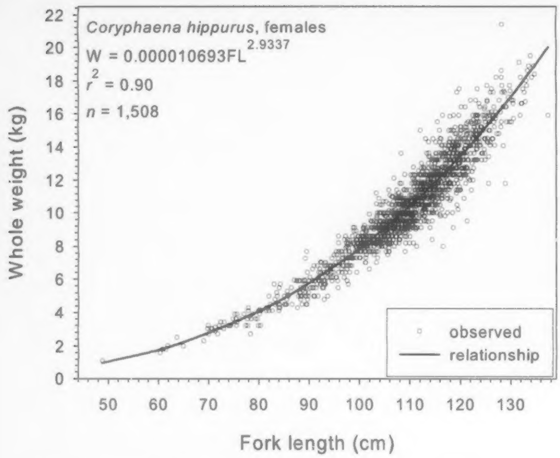

Figure 1.—Whole weight-on-fork length relationship for female dolphinfish measured at the Honolulu fish auction, March 1988–November 1989.

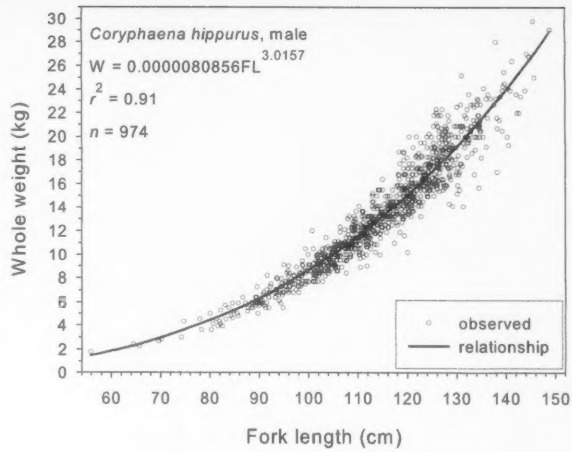

Figure 3.—Whole weight-on-fork length relationship for male dolphinfish measured at the Honolulu fish auction, March 1988–November 1989.

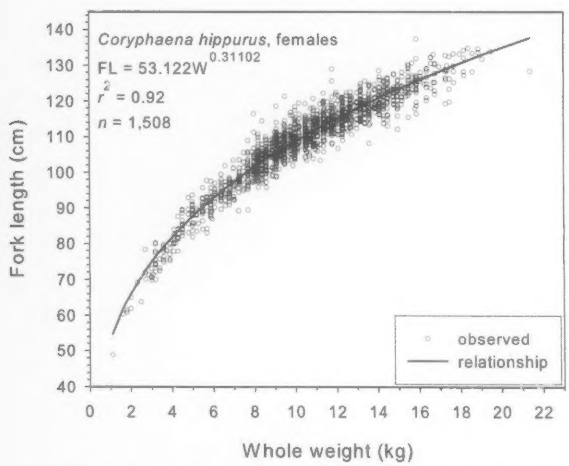

Figure 2.—Fork length-on-whole weight relationship for female dolphinfish measured at the Honolulu fish auction, March 1988–November 1989.

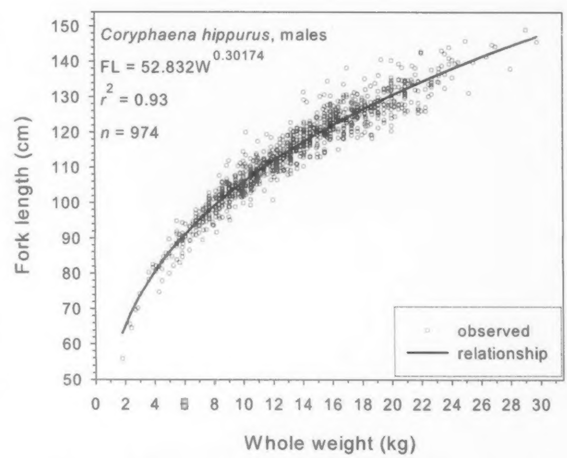

Figure 4.—Fork length-on-whole weight relationship for male dolphinfish measured at the Honolulu fish auction, March 1988–November 1989.

112); males ranged from 79.1 to 148.7 cm FL ($n = 59$). Cursory examination of both cruise and auction measurements indicated four outliers for data collected at the auction. The latter were deleted. With lengths trimmed to include only 110–145 cm FL, the cruise-sampled fish indicated that sex had no significant effect on the wahoo W-L parameters (coefficient: p = 0.18, exponent: p = 0.17, $n = 144$; Table 7). Wahoo L-W data collected at the auction were trimmed to include fish in the 108–160 cm FL range. Except for January and July, most months covered about 90% or more of the trimmed range. The effect of month as a categorical factor on W-L coefficients was significant ($p < 0.01$; Table 8).

After completing hypothesis testing, subsequent analyses used untrimmed data. Monthly nonlinear W-L relationships were calculated (Table 9). Nonlinear W-L and L-W relationships with sexes pooled (Table 10; Fig. 8, 9) and a log-linearized W-L relationship were also fitted (Table 10). Monthly predicted mean weights at 120, 135, and 150 cm reference FL were plotted to illustrate the variability of condition over the year for wahoo (Fig. 10). Reference lengths were three equally spaced lengths well in the observed length range, except for

Table 4.—Nonlinear and log-linearized whole weight (W)-on-fork length (FL) and FL-on-W relationships for female and male central North Pacific dolphinfish measured at the Honolulu fish auction from March 1988 through November 1989.

		Model $Y = aX^b$			Exponent		Coefficient		Size range			
									W (kg)		FL (cm)	
Relation	Sex	r^2	se	n	b	se	a	se	Min.	Max.	Min.	Max.
W on FL	F	0.90	1.003	1508	2.9337	0.024932	1.0693E-5	1.3251E-6	1.1	21.4	48.8	137.4
FL on W		0.92	3.313		0.31102	0.0024477	53.122	0.31096				
W on FL	M	0.91	1.398	974	3.0157	0.028491	8.0856E-6	1.1924E-6	1.8	29.8	55.8	149.0
FL on W		0.93	3.489		0.30174	0.0026917	52.832	0.37804				
FL on W	pooled	0.91	3.694	2482	0.29243	0.0018267	54.917	0.25135	1.1	29.8	48.8	149.0

		$\log Y = \log a + b^* \log X$											
	Sex	r^2	se	n	rss	b	se	log a	se				
logW on logFL	F	0.93	0.0936619	1508	13.2114	2.93849	0.0202043	−11.4741	0.0946739	1.1	21.4	48.8	137.4
logW on logFL	M	0.94	0.0964733	974	9.0465	3.07984	0.024875	−12.0368	0.117757	1.8	29.8	55.8	149.0

Additional statistical data	Female	Male
mean iogFL = mean X	4.68432	4.7323
Σ(logFL−mean logFL)² =Σx²	21.4901	15.0414
Σ(logFL−mean logFL)*(logW−mean logW) = Σxy	63.1485	46.325
Σ(logW−mean logW)² = Σy²	198.773	151.72
mean logW = mean Y	2.29069	2.53796

Table 5.—Monthly nonlinear whole weight (W)-on-fork length (FL) relationship for female dolphinfish measured at the Honolulu fish auction from March 1988 through November 1989.

	Model: $W = aFL^b$			Exponent		Coefficient		Size range			
								Weight (kg)		Length (cm)	
Month	r^2	se	n	b	se	a	se	Min.	Max.	Min.	Max.
January	0.97	0.748	22	3.0011	0.11856	7.8127E-6	4.7181E-6	2.0	18.9	64.9	134.6
February	0.86	0.931	139	2.8589	0.090958	1.4599E-5	6.733E-6	1.8	19.5	60.8	133.9
March	0.86	0.946	186	2.9927	0.087897	7.8866E-6	3.4993E-6	2.7	18.6	77.4	124.9
April	0.85	0.921	209	2.8948	0.078061	1.2882E-5	5.1142E-6	4.8	16.7	87.8	125.7
May	0.86	0.955	312	2.7930	0.06116	2.0688E-5	6.4092E-6	2.3	17.4	69.0	137.4
June	0.91	0.873	53	2.6506	0.10606	4.0557E-5	2.1892E-5	4.2	16.7	80.1	132.9
July	0.91	0.851	41	2.7152	0.12534	2.9755E-5	1.8905E-5	4.8	17.4	83.1	129.9
August	0.91	0.955	148	2.8138	0.075438	1.8811E-5	7.2392E-6	1.6	18.6	60.3	134.8
September	0.91	1.042	109	2.8001	0.096936	2.0609E-5	1.0256E-5	1.1	17.7	48.8	129.8
October	0.93	1.031	161	2.7826	0.072439	2.2767E-5	8.4965E-6	1.8	19.1	61.4	133.4
November	0.91	1.215	128	2.9011	0.086282	1.2437E-5	5.5010E-6	3.0	21.4	70.5	134.2

July when the largest fish was measured at 146 cm FL. The condition of wahoo was highest in May and lowest in July or August for all reference sizes. The differences in monthly predicted mean weights between the highest and lowest condition were 7.5% at 120 cm FL, 8.0% at 135 cm FL, and 8.7% at 150 cm FL. Unlike dolphinfish, there was no suggestion of more than one cycle per year.

Discussion

Previous studies have dealt briefly with sexual dimorphism of dolphinfish. Some have plotted the W-L relationships separately for males and females (Beardsley, 1967; Rose and Hassler, 1968; Chatterji and Ansari, 1985; and Oxenford and Hunte, 1986b) or

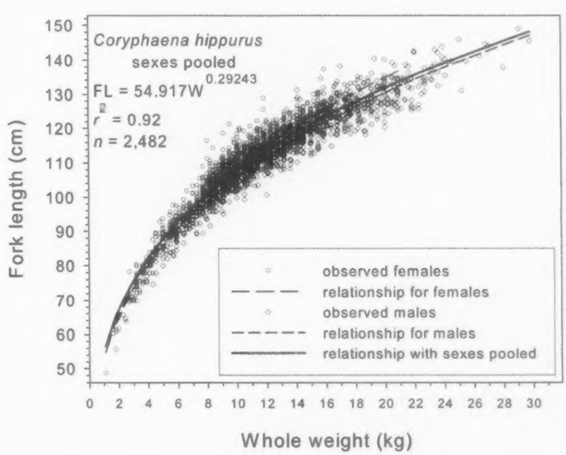

Figure 5.—Fork length-on-whole weight relationship for dolphinfish with sexes pooled.

provided separate equations for males and females (Lasso and Zapata, 1999; Massuti et al., 1999) without providing a statistical justification for the separation. Wang (1979) tabulated the mean W-L separately for males and females. Schuck (1951) and Beardsley (1967) only mentioned that the mean W-L for males was greater than females. This study statistically tested the difference in the W-L coefficients of female and male dolphinfish (Table 1) and the em-

Table 6.—Monthly nonlinear whole weight (W)-on-fork length (FL) relationship for male dolphinfish measured at the Honolulu fish auction from March 1988 through November 1989.

	Model: $W = aFL^b$			Exponent		Coefficient		Size range: Weight (kg)		Size range: Length (cm)	
Month	r^2	se	n	b	se	a	se	Min.	Max.	Min.	Max.
January	0.98	0.794	10	3.1774	0.14223	3.7031E-6	2.7455E-6	5.2	24.5	84.7	139.8
February	0.94	1.196	63	2.9658	0.086455	9.9674E-6	4.4532E-6	2.7	27.0	69.6	144.2
March	0.94	1.046	133	2.9223	0.05823	1.1973E-5	3.5847E-6	3.6	23.4	80.3	142.7
April	0.91	1.199	191	3.1074	0.065493	5.1216E-6	1.7261E-6	5.5	28.0	88.3	143.0
May	0.91	1.155	224	2.9549	0.056821	1.0779E-5	3.1346E-6	2.4	29.8	64.5	149.0
June	0.90	1.456	33	2.7511	0.16585	2.9241E-5	2.4969E-5	5.7	20.2	83.0	136.0
July	0.97	0.966	19	3.1396	0.16044	4.428E-6	3.7116E-6	2.9	23.2	70.1	136.0
August	0.90	1.680	81	2.9	0.11310	1.4517E-5	8.5439E-6	3.0	26.8	74.2	144.7
September	0.93	1.441	59	2.9870	0.12856	9.6313E-6	6.4295E-6	1.8	22.5	55.8	134.7
October	0.87	1.897	102	2.7954	0.11354	2.4323E-5	1.4378E-6	2.3	25.5	65.7	142.1
November	0.93	1.332	58	2.853	0.10641	1.8129E-5	1.0037E-5	3.9	23.9	82.5	143.9

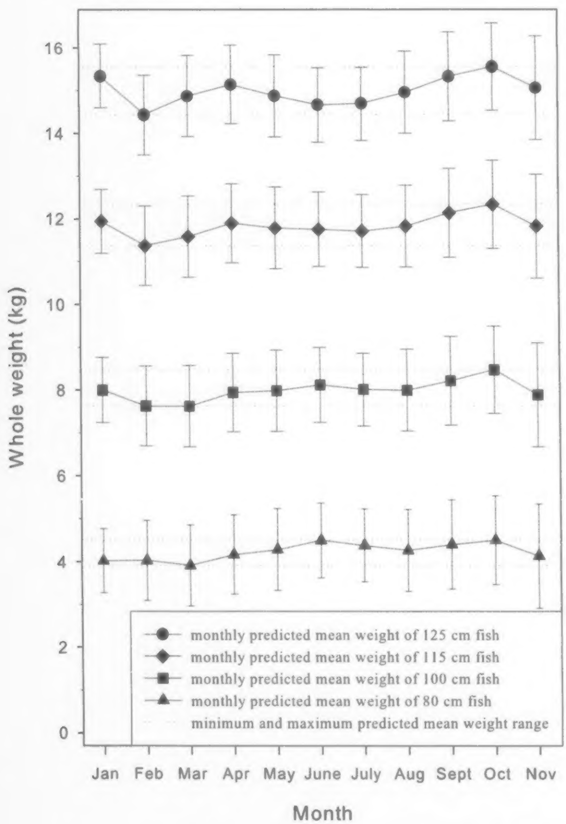

Figure 6.—Plots of monthly predicted mean whole weights with standard errors for female dolphinfish at 80, 100, 115, and 125 cm fork length.

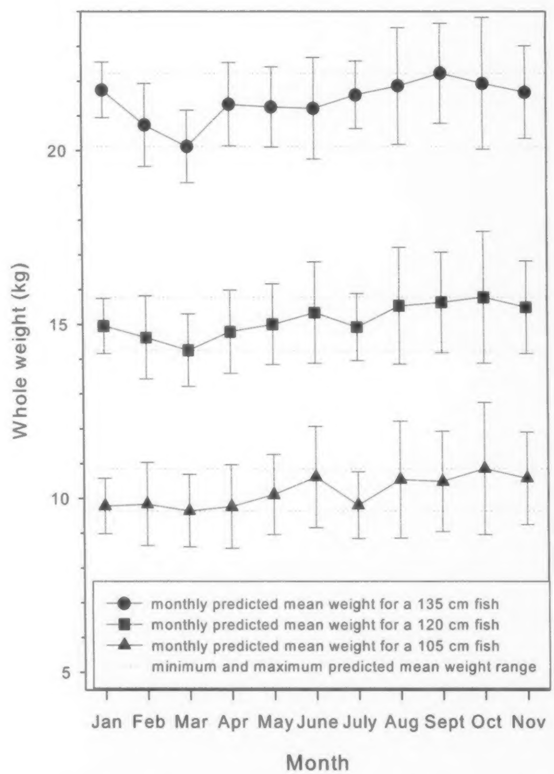

Figure 7.—Plots of monthly predicted mean whole weights with standard errors for male dolphinfish at 105, 120, and 135 cm fork length.

pirical difference in predicted mean W-L can be viewed in Figure 5. Bannister (1976) visually compared plots of W-L relationships of dolphinfish caught in the Mediterranean with those caught off North Carolina in the western Atlantic (Rose and Hassler, 1968). Oxenford and Hunte (1986b) plotted and visually compared the W-L relationships of dolphinfish from North Carolina (Rose and Hassler, 1968), Florida (Beardsley, 1967), and Barbados (their study) and found little difference in the W-L relationships among these locations in the western and central Atlantic. Estimated parameters and other statistical data for log-linearized W-L relationships of Hawaiian dolphinfish are provided so others can statistically compare W-L coefficients of dolphinfish from other areas and especially other areas of the Pacific Basin (Table 4).

The large variances in the W-L relationships for wahoo and dolphinfish were a result of the wide range of well-conditioned-to-poor-conditioned individuals in the samples. Reduced condition was probably a result of energy drain by spawning activities. Based on observation of captive dolphinfish that appeared to spawn every second day at the National Marine Fisheries Service

Table 7.—Multiple regression analysis evaluating the effect of sex on the log-linearized whole weight-on-log fork length (range 110–145 cm) relationships for troll caught wahoo from the Northwestern Hawaiian Islands 1977–1984.

Parameter	Estimate	se	t test	p-value
Coefficient for males	−22.701	0.639	−35.47	<0.01
Exponent for males	3.528	0.089	39.28	<0.01
Difference in coefficient for females	1.321	0.970	1.36	0.18
Difference in exponent for females	−0.187	0.135	−1.37	0.17

$r^2 = 0.95$
$n = 144$
Durbin-Watson statistics = 1.951, p = 0.39

Table 8.—Summary of generalized linear model type III sum of squares analysis evaluating the effects of month (of landing) on the log-linearized whole weight-on-log fork length (FL, range 108–160 cm) relationship for wahoo measured at the Honolulu fish auction from July 1988 through November 1989.

Source	Sum of squares	df	Mean square	F-ratio	p-value
logFL	40.2455	1	40.2455	5226.36	0.00
Month	0.178857	9	0.019873	2.58	<0.01
Month*logFL	0.179448	9	0.0199387	2.59	<0.01
Residual	8.20101	1065	0.00770048		
Total	112.821	1084			

Table 9.—Monthly nonlinear whole weight (W)-on-fork length (FL) relationship for wahoo measured at the Honolulu fish auction from July 1988 through November 1989.

	Model: $W = aFL^b$			Exponent		Coefficient		Size range: Weight (kg)		Size range: Length (cm)	
Month	r^2	se	n	b	se	a	se	Min.	Max.	Min.	Max.
January	0.95	1.059	19	3.1191	0.15491	3.3891E-6	2.8705E-6	9.1	27.7	120.7	159.3
February	0.92	1.434	46	2.9131	0.12715	9.5945E-6	6.4853E-6	3.2	23.6	71.3	173.9
March	0.93	1.327	59	3.1704	0.11997	2.6730E-6	1.7757E-6	3.0	33.6	87.4	166.5
April	0.94	1.189	99	3.2147	0.083539	2.1775E-6	9.998E-7	3.6	26.8	90.4	153.3
May	0.92	1.497	276	3.1303	0.053045	3.4287E-6	9.9812E-7	4.1	43.2	94.2	172.5
July	0.91	0.883	87	3.0881	0.093154	3.9022E-6	1.9337E-6	5.4	19.3	103.3	145.5
August	0.92	1.215	379	3.0711	0.044664	4.4064E-6	1.0605E-6	3.9	27.3	91.7	159.9
September	0.90	1.572	85	2.8859	0.085422	1.0734E-5	4.8932E-6	7.7	33.6	107.0	173.1
October	0.91	1.363	77	3.0431	0.10241	4.9982E-6	2.7074E-6	1.8	26.4	71.3	160.9
November	0.96	0.996	34	3.2022	0.10037	2.2782E-6	1.2158E-6	3.0	26.4	84.0	163.3

Table 10.—Nonlinear and log-linearized whole weight (W)-on-fork length (FL) and FL-W relationships for wahoo measured at the Honolulu fish auction from July 1988 through November 1989.

	Model $Y = aX^b$			Exponent		Coefficient		Size range: W (kg)		Size range: FL (cm)	
Relation	r^2	se	n	b	se	a	se	Min.	Max.	Min.	Max.
W on FL	0.92	1.330	1161	3.3034	0.024087	1.4157E-6	1.8177E-7	1.8	43.2	71.3	173.1
FL on W	0.94	3.3141	1161	0.27500	0.0020360	63.434	0.33973				

	$\log W = \log a + b^*\log FL$				Slope		Intercept	
	r^2	se	n	rss	b	se	$\log a$	se
logW on logFL	0.95	0.0895019	1161	9.28428	3.45171	0.0236125	−14.1959	0.114339

Additional statistical data for log linearized model	
mean logFL = mean X	4.84104
$\Sigma(\log FL - \text{mean} \log FL)^2 = \Sigma x^2$	14.3675
$\Sigma(\log FL - \text{mean} \log FL)^*(\log W - \text{mean} \log W) = \Sigma xy$	49.5926
$\Sigma(\log W - \text{mean} \log W)^2 = \Sigma y^2$	185.558
mean logW = mean Y	2.58022

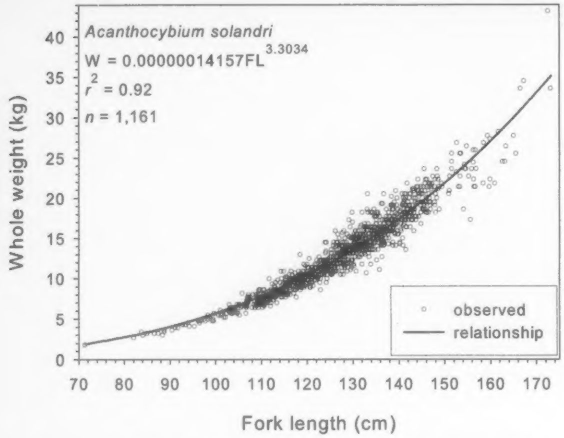

Figure 8.—Whole weight-on-fork length relationship for wahoo measured at the Honolulu fish auction, July 1988–November 1989.

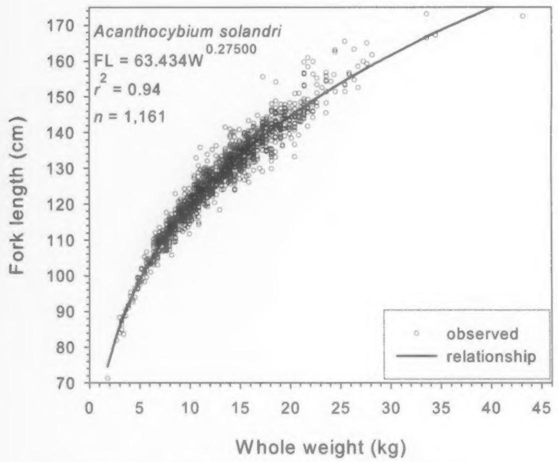

Figure 9.—Fork length-on-whole weight relationship for wahoo measured at the Honolulu fish auction, July 1988–November 1989.

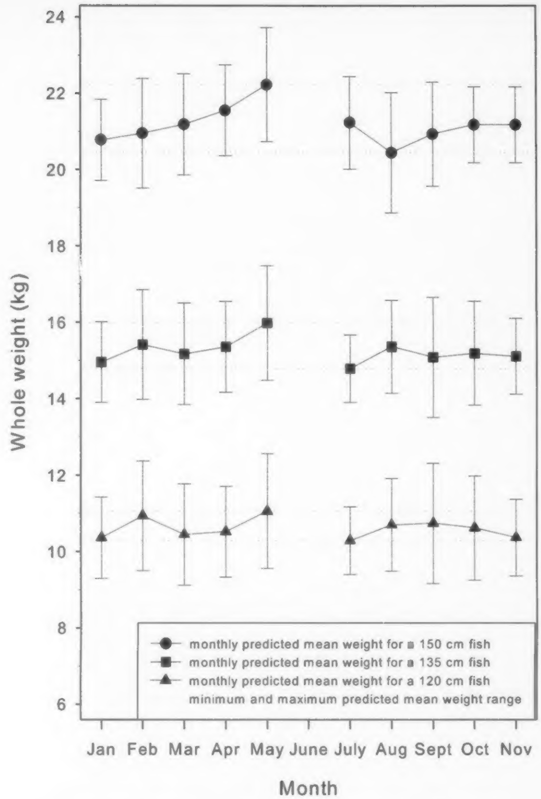

Figure 10.—Plots of monthly predicted mean whole weights with standard errors for wahoo at 120, 135, and 150 cm fork length.

Kewalo Research Facility, weight lost by a mating pair was clearly noticeable after 2 months of spawning. A recovery of condition was also observed when the mating pair was separated.[7]

The classic modal cycle in condition (LeCren, 1951) seen in Hawaii-caught wahoo (Fig. 10) and suggestion of bimodality in the condition factor of dolphinfish (Fig. 6, 7) may have an interesting relationship to patterns of seasonal abundance of these species in Hawaii fisheries. Wahoo catch per trip has one mode during May–September for all three fisheries, whereas dolphinfish catch per trip in the Hawaii longline, troll, and handline fisheries is bimodal, peaking at its highest in April and high again during October–November.[8,9] The seasonality of the catch mirrors the catch rates, and although there is interannual variation in this pattern, the typical pattern was observed during all of the years of this study.[2]

The condition and abundance of wahoo appear to be related to a simple annual reproductive cycle. Ovaries collected from around the main Hawaiian Islands and at the edge of the banks in the Northwestern Hawaiian Islands contain oocytes with yolk globules, oo-

[7]Kazama, T. K. 1988. Unpubl. data on file at the Pac. Isl. Fish. Sci. Cent., Natl. Mar. Fish. Serv., 2570 Dole Street, Honolulu, HI 96822-2396.

[8]Boggs, C. H. 1991. A preliminary examination of catch rates in Hawaii's trolling and handline fisheries over a period of domestic longline fishery expansion. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-91-05, 62 p.

[9]Skillman, R. S., and G. L. Kamer. 1992. A correlation analysis of Hawaii and foreign fishery statistics for billfishes, mahimahi, wahoo, and pelagic sharks, 1862–78. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-92-05, 44 p.

cytes that had begun to hydrate, or have post ovulatory follicles in the summer months. In September, oocytes in ovaries are in the atretic stage[10] indicating the end of the spawning season. The condition of wahoo is highest in May before the spawning season and declines through the spawning season reaching a minimum in July–August (Fig. 10). Catch peaked in summer, during the spawning season, suggesting that wahoo may gather near the islands to spawn.

Such a pattern is also seen in central North Pacific swordfish, *Xiphias gladius*, which spawn close to the islands and large banks of the Hawaiian archipelago (DeMartini et al., 2000). Swordfish condition is highest in February–March (at the beginning of its spawning period) and is lowest in July–August (at the end of the spawning period) (Uchiyama et al., 1999). The Hawaii longline fishery for swordfish follows the concentration of fish from the subtropical convergence far north of the islands in January–February down closer to the islands during March–May (Bigelow et al., 1999). The only appreciable occurrence of swordfish in coastal Hawaii fisheries subsequently occurs in June.[8] This pattern in catch rates suggests a southward reproductive migration during the first 6 months of the year (DeMartini et al., 2000). For the rest of the year swordfish are scarce until they appear again far to the north around the subarctic convergence in November–December (Bigelow et al., 1999).

We postulate that migration related to reproduction may also explain some of the seasonality in catch rates of wahoo near the Hawaiian Islands. Eight wahoo ovaries collected > 50 mi. (>93 km) from shore were undeveloped or in the early stages of development.[10] The occurrence of wahoo larvae in plankton tows within 15 mi. (28 km) from shore of the islands in the main Hawaiian Islands has been reported during June–September by Miller et al. (1979) and by Boehlert and Mundy (1996). It appears that wahoo may migrate from the open ocean to the islands and banks to reproduce and then leave the islands and banks to feed in the open ocean. Surface currents[11] and eddies generated in the island wakes (Wyrtki et al., 1967; Patzert, 1969; Barkley, 1972) are mechanisms that could transport larvae and juveniles to the open ocean.

Matsumoto (1967) found 38 wahoo larvae and juveniles in 1,643 samples from oblique plankton tows collected from the open ocean, so a limited amount of spawning could also occur offshore. However, a move to nearshore waters in May for spawning throughout the summer would be consistent with the increase in condition and catch rates in the nearshore fisheries. An analysis now underway of geographic patterns and shifting of high catch rate areas visited by the Hawaii-based longline fleet suggests that the highest abundance areas for wahoo within range of the fleet are southwest of the islands year round but spread northward into coastal banks distributed over 1,200 mi. in summer.[12]

The bimodal pattern of relative monthly abundance and how it could relate to spawning and condition of dolphinfish appears more complex than for swordfish or wahoo. Peak spawning occurs in April–May[13] coincident with peak catch rates and increased condition. However, spawning continues year round near the islands[14], the condition maximum occurs late in the year during the second mode in catch rates, and the condition minimum follows in February.

We suggest that the spring peak in catch rate and the summer decline in catch and condition could be related to spawning aggregation near the Hawaiian Islands. Dolphinfish ovaries collected in the main Hawaiian Islands and around the large shallower banks with low islands or coral atolls to the northwest in the Northwestern Hawaiian Islands all appear ready to spawn or had just spawned, based on presence of hydrated eggs or post-ovulatory follicles. Relatively few ovaries of dolphinfish collected > 70 mi. (>130km) from shore developed hydrated eggs, but the majority of other dolphinfish ovaries were undeveloped or appeared to be reabsorbing the vitellogenic oocytes before they had reached maturity.[14]

The September–October maximum spawning condition coincident with rise in coastal catch rates October–November could result from a return to the islands of the Hawaiian archipelago after a nonspawning interval offshore. However, the increased condition could also suggest that fish return from more productive waters near the southern boundary of the subtropical convergence to the north. An analysis now underway[12] of geographic patterns and shifting of high catch rate areas visited by the Hawaii-based longline fleet suggests that the highest abundance areas shift far to the north during summer. And the February–March minimum condition could reflect energy losses during winter spawning.

Summary

We postulate two possible migration scenarios which might explain changes in dolphinfish condition. In the first scenario, well conditioned fish enter nearshore (< 50 mi. or < 93 km) waters from the open ocean, and engage in intense reproductive activities, resulting in weight loss. The dolphinfish, now in an emaciated state, return to the open ocean. In the summer, the density of dolphinfish near the main Hawaiian Islands is low, perhaps because they migrate offshore to avoid their main predator, the blue marlin, *Makaira nigricans*, which increase in numbers in nearshore waters

[10]Uchiyama, J. H., and J. H. Prescott. 2004. Unpubl. data on file at Pacific Islands Fisheries Science Center, Natl. Mar. Fish. Serv., 2570 Dole Street, Honolulu, HI 96822-2396.

[11]Firing, J., R. Hoeke, and R. Brainard. 2004. Surface velocity and profiling drifters track potential larval pathways in Northwestern Hawaiian Islands. Poster presentation at Northwestern Hawaiian Islands Third Scientific Symposium, 2–4 Nov. 2004, Hawaii Convention Center, Honolulu.

[12]Kobayashi, D. 2004. Unpubl. data on file at Pac. Isl. Fish. Sci. Cent., Natl. Mar. Fish. Serv., 2570 Dole Street, Honolulu, HI 96822-2396.

[13]Burch, R. K. Biologist. Waikiki Aquarium, Honolulu, HI 96815. Personal commun., May 1982.

[14]Uchiyama, J. H., and R. A. Skillman. Unpubl. data on file at Pac. Isl. Fish. Sci. Cent., Natl. Mar. Fish. Serv., 2570 Dole Street, Honolulu, HI 96822-2396.

to reproduce (Hopper, 1990). While offshore during the summer, dolphinfish improve their condition during a nonreproductive period. When they return in late September and October, their condition is at their highest level. A similar nearshore-offshore spawning movement for dolphinfish has been suggested by Wheeler and Ommanney (1953), Williams (1953), Kojima (1955), Williams and Newell (1957), and Arocha et al. (1999).

In the second possible complementary migration scenario, juvenile dolphinfish migrate northward in summer up to ~600 mi. (1,100 km) from the main Hawaiian Islands to the southern boundary of the subtropical convergence front where productivity is high. There they fatten up and then migrate southward back to the Hawaiian archipelago to reproduce again nearshore. This model would be similar to the migration model described by Oxenford and Hunte (1986a). A clearer picture may emerge from the longline fleet catch rate analysis. And the February–March condition maxima suggest that field researchers should look for evidence of an early peak in spawning.

Acknowledgments

We thank the United Fishing Agency and the fishing boat captains, buyers, and employees at the fish auction for permitting us to collect data. We are indebted to A. Chun who diligently collected and accurately recorded the data early in the morning for all those months. Greatly appreciated are the statistical advice and review provided by M. McCracken and the critical comments and preview of plots of dolphinfish and wahoo CPUE per 1-degree by 1-degree area of the Hawaii-based fishery provided by D. Kobayashi. We also thank H. Oxenford, K. Bigelow, E. DeMartini, and G. Dinardo for their useful suggestions.

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Skimmer Trawl Fishery Catch Evaluations in Coastal Louisiana, 2004 and 2005

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Introduction

The majority of penaeid shrimp (Penaeidae) harvested in the Gulf of Mexico and southeastern Atlantic are taken with bottom-otter trawls. Skimmer

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ABSTRACT—Fishery observers collected data from 307 tows during 96 trips aboard skimmer trawl vessels in Louisiana's coastal waters from September 2004 through June 2005 to estimate catch rates of target and nontarget species, including sea turtles (Cheloniidae and Dermochelyidae), by area and season during commercial shrimping operations. About 16,965.7 kg of total catch were recorded during 517.0 hours of fishing operations. Based on weight extrapolations from species composition samples, penaeid shrimp (Penaeidae) dominated the catch at 66%, followed by finfish at 19%, nonpenaeid shrimp crustaceans at 7%, discarded penaeid shrimp at 6%, and debris at 3%. Noncrustacean invertebrates comprised less than 1%. Catch rates in kilograms per hour by category was 21.6 for penaeid shrimp, 6.2 for finfish, 2.2 for nonpenaeid crustaceans, 1.8 for discarded penaeid shrimp, and 0.9 for debris. White shrimp, Litopenaeus setiferus, *other penaeid shrimp, and Gulf menhaden,* Brevoortia patronus, *were the top three dominant species by weight. Seasonally, a higher catch rate was observed from May through August 2005 for penaeid shrimp as compared with the September through December 2004 period. Conversely, the September through December 2004 period experienced a higher catch rate for finfish than during May through August 2005. No sea turtle interactions were documented.*

trawls (Fig. 1), an alternative method for shrimp capture, are paired-framed nets typically used in inshore waters. The gear can be passive, relying on tidal currents to move shrimp into the nets, or, more commonly, a vessel pushes the nets through the water column. Once the nets are lowered into the water, only the bags (cod ends) are picked up to remove the catch; the mouths of the skimmer trawls are continually fishing.

Skimmer trawls have been documented in Louisiana, North Carolina, and, more recently, in other coastal states in the Gulf of Mexico (Epperly et al., 2002). In 1992, the number of skimmer trawl licenses acquired in Louisiana was 1,836; by 2000, the number approximately doubled to 3,655 (Epperly et al., 2002). In North Carolina, skimmer trawls target white shrimp, *Litopenaeus setiferus*, in late summer through fall in Pamlico and Core Sounds. About 3,587 trips occurred in 2002 in North Carolina using skimmer trawl gear, with trips typically less than 24 h in length (Daniel[1]).

Hein and Meier (1995) reported on the history and use of skimmer trawls in coastal Louisiana. As reflected by increased license sales and based on dockside interviews, the advantages of skimmer trawls over the traditional otter trawl were presented. Increased efficiency relative to gear retrieval, better survivability and condition of both target and nontarget species, greater and more effective coverage of fishing areas, and improved safety were among the advantages given. Disadvantages included restricted fishing depth, greater care required to avoid obstructions at night, bottom damage resulting from improperly tuned gear, and vessel instability when underway.

Coale et al. (1994), using a skimmer trawl designed by a Louisiana commercial shrimp industry member, compared catch rates between skimmer and otter trawls in the inshore waters of North Carolina. They reported that the skimmer trawl caught less bycatch, had lower bycatch rates, and a lower fish-to-shrimp ratio ($\bar{x}$= 1.38) compared with the otter trawl during the peak white shrimp season. Moreover, white shrimp comprised 23.3% of the total weight in the skimmer trawl. In the otter trawl, white shrimp accounted for 5.1% of the total biomass. Conversely, brown shrimp, *Farfantepenaeus aztecus*, constituted 6.1% of the total catch in the skimmer trawl, compared with 16.8% of total biomass in the otter trawl. The authors also reported greater survivability of organisms captured in the skimmer trawl than those obtained in the otter trawl.

The performance of the standard high-profile vs. low-profile skimmer trawls in North Carolina was examined by Hines et al. (1999). Catch rates for penaeid shrimp, including penaeid discards, were significantly lower in the low-profile net as opposed to the high-profile net. By species, brown shrimp catches were lower by 39.1%; no significant difference was detected between the two net designs for pink shrimp, *Farfantepenaeus duorarum*. The authors attributed this to low pink

[1]Daniel, L. 2004. North Carolina Division of Ma-rine Fisheries, Morehead City. Personal commun.

shrimp abundance. No white shrimp were present during the study. Total finfish by weight was similar between the two net designs, with finfish comprising 67.5% in the low-profile net, and 62.0% in the high-profile net.

Rudershausen and Weeks (1999) discussed the advantages of skimmer trawls over conventional otter trawls used in North Carolina. These included reducing bycatch, minimizing disturbance to the benthic habitat, and increasing bycatch survivability. The authors compared steel and aluminum skimmer trawl frames to determine if fuel efficiency would increase with the lighter, yet more expensive, aluminum construction; there was no significant difference in fuel efficiency between materials.

Currently, there are no turtle excluder device (TED) or bycatch reduction device (BRD) requirements for skimmer trawls; however, limited tow-time restrictions apply due to the potential for sea turtle interactions. Tow times are established by individual states. Prior to this research effort, very limited historical and no known current data relative to catch composition, directed effort, or operational aspects for the Gulf of Mexico skimmer trawl fishery were available.

In September 2004, the NMFS Southeast Fisheries Science Center's Galveston Laboratory, in cooperation with the shrimp industry, initiated observer coverage of the skimmer trawl fishery operating in the U.S. Gulf of Mexico, exclusively within coastal waters of Louisiana. The primary objectives of this research were to estimate catch rates of target and nontarget species, including sea turtles, by area and season during commercial shrimping operations.

Methods

NMFS-approved observers were placed on cooperating skimmer trawl vessels targeting penaeid shrimp. Ninety-six skimmer trawl trips were observed from September 2004 through June 2005. A total of 307 tows during 114 sea days of observations (Fig. 2) were completed during the study period. No attempt was made to direct fishing location or to modify normal commer-

Figure 1.—A skimmer trawl vessel showing the paired-frame net design.

Figure 2.—Distribution of sampling effort (tows) aboard skimmer trawl vessels.

cial operations. Effort allocation was based on vessel availability and current commercial effort trends by area and season.

Vessel length, hull construction material, gross tonnage, engine horsepower, and crew size information were obtained for each vessel. Characteristics related to net type and other associated gear were recorded at the start of each trip or when changes were made. Bottom time, vessel speed, and operational aspects relative to each net were documented for each tow.

Fishery-specific data were collected from one randomly selected net from each tow. Total catch and shrimp weights were recorded (i.e. not extrapolated and based on one net per tow). A subsample (about 20% of the total catch weight) was processed for species composition. Species weight and number were obtained from the subsample. A detailed description of the sampling procedures is contained in the NMFS Characterization of the U.S. Gulf of Mexico and Southeastern Atlantic Otter-trawl and Bottom Reef Fish Fisheries Observer Training Manual (NMFS[2]).

Species total weights and numbers were extrapolated from subsample weight to the total catch weight, and are also based on one net per tow. In the absence of a weight or number for a given species, the entire tow was set aside from the analysis.

Unique species, family, taxa, etc. (now referred to as species) were recorded. Species were placed into the following categories: penaeid shrimp, nonpenaeid shrimp crustaceans, fish, noncrustacean invertebrates, and debris (e.g. rocks, logs, trash). Debris counts, where present, were entered as a default of one and accounted for less than 1% based on one unit of debris for each tow.

Overall catch rates were presented for all years, areas, seasons, and depths. Catch rate estimates were also examined by year and season. Seasonal categories are as follows: January through April, May through August, and September through December.

Biological measurements were recorded in metric units. Vessel, gear, and depth measurements followed current standards for the fisheries (i.e. U.S. system equivalents) as related to relevant regulatory mandates.

For graphing purposes, percent values were rounded to the nearest whole number. The order of the categories presented in the graphs varied. Moreover, sample size used for extrapolation purposes varied by weight and number.

All data were entered into the southeast regional shrimp trawl bycatch database that has been developed since 1992 though a southeast regional program conducted by NMFS in cooperation with commercial fishing organizations and interests, state fishery management agencies, and universities. This database is housed and managed at the NMFS Southeast Fisheries Science Center's Galveston Laboratory where final data sets are archived. Summarized data (i.e. individual identifiers removed) are available for use by all interested stakeholders.

Results

Overview

Three observers collected data from 307 tows from ninety-six trips in coastal waters of Louisiana from September 2004 to June 2005. Based on these 307 tows (517.0 h), 16,965.7 kg of total catch were recorded based on one net from each tow. Retained shrimp species comprised 10,423.2 kg (heads-on), or 61.4% of the total weight. Catch-per-unit-of-effort (CPUE) for shrimp was 20.2 kg/h.

Three hundred and four tows contained species characterization data. Penaeid shrimp percent composition extrapolated from these subsamples was 66.1%. Extrapolated CPUE for shrimp based on subsamples was 21.6 kg/h.

A total of 63 unique species were collected. There were 56 species of fish and 4 species of penaeid shrimp. Crustaceans and invertebrates had one unique species each. Logs, rocks, etc. were placed in miscellaneous debris.

Vessels, Gear, and Tow Characteristics

Three unique vessels participated in the study. Overall vessel length ranged from 34 to 42 ft with 39.7 ft the average (± 4.0 s.d.). All vessels were of fiberglass construction and had ice storage capacity.

Based on a per tow basis, headrope length was 16.0 ft (± 0.0 s.d). Two nets were pushed on each tow. Nets were not equipped with TED's or BRD's. Towing speed ranged from 0.9 to 3.0 kn and averaged 1.8 kn (± 0.3 s.d.).

Tow depth averaged 1.3 fathoms (± 0.2 s.d) and ranged from 0.8 to 2.3 fathoms. Tow time ranged from 0.2 to 4.3 h, with an average tow time of 1.7 h (± 0.4 s.d). The majority of tows occurred between dawn and late afternoon; average trip length was 1 day.

Extrapolated Species Composition by Categories: Percent and CPUE

Based on weight extrapolations from species composition samples by category for both years, all areas, seasons, and depths (Fig. 3), penaeid shrimp dominated the catch at 66%, followed by fish species at 19%, nonpenaeid shrimp crustaceans at 7%, discarded penaeid shrimp at 6%, and debris at 3%.[3] Noncrustacean invertebrates comprised less than 1%. CPUE (kg/h) by category was 21.6 for penaeid shrimp, 6.2 for fish, 2.2 for crustaceans, 1.8 for discarded penaeid shrimp, and 0.9 for debris.

Extrapolated numbers from species composition samples by category for all years, areas, seasons, and depths are presented in Figure 4. Penaeid shrimp were dominant by number at 89%, followed by fish at 8%, discarded penaeid shrimp at 2%, and nonpenaeid shrimp crustaceans at 1%. As previously mentioned, tows where no counts were obtained (75) for a given species were set aside for the purpose of this analysis. CPUE estimates in numbers per hour for the category components were 6,498 for

[2]NMFS. 2002. Characterization of the U.S. Gulf of Mexico and southeastern Atlantic otter trawl and bottom reef fish fisheries. Observer Training Manual. NMFS Southeast Fisheries Science Center, Galveston Laboratory, Galveston, Tex.

[3]Percentages may not equal 100% due to rounding.

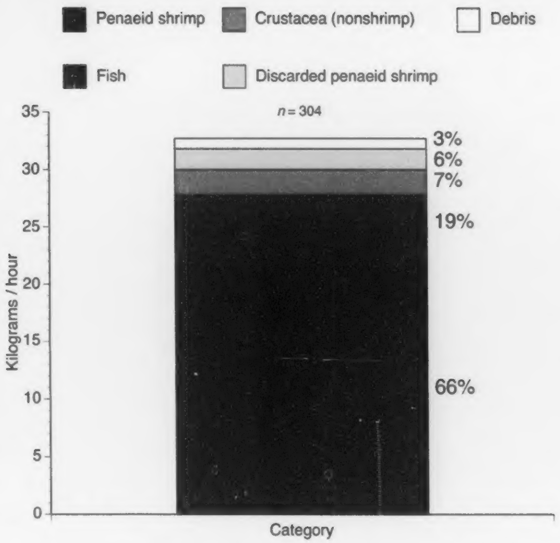

Figure 3.—CPUE and percent species composition by weight and category from skimmer trawl tows. Percentage does not equal 100% due to rounding.

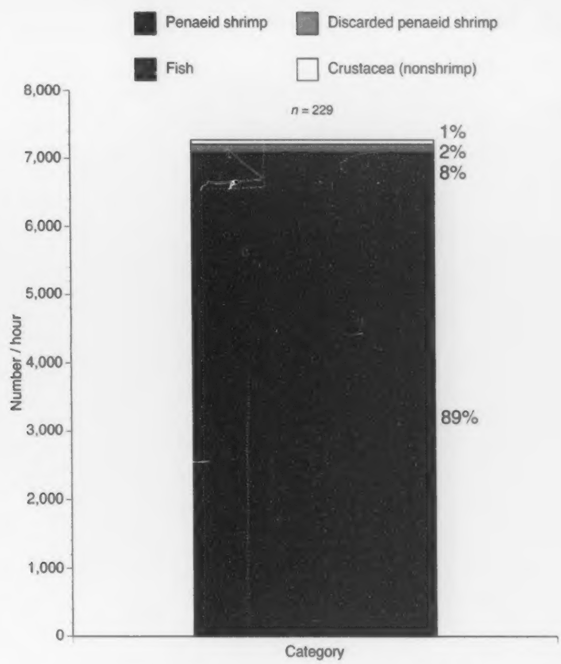

Figure 4.—Percent species composition by number and category from skimmer trawl tows.

penaeid shrimp, 595 for fish, 118 for discarded penaeid shrimp, and 66 for crustaceans.

Extrapolated Species Composition by Species: Percent and CPUE

Weight extrapolations from the species composition samples for both years, all areas, seasons, and depths (Fig. 5) indicate that white shrimp comprised 49% of the total catch; followed by penaeid shrimp at 17%; Gulf menhaden, *Brevoortia patronus*, at 8%; blue crab, *Callinectes sapidus*, at 7%; discarded penaeid shrimp at 6%; debris at 3%; Atlantic croaker, *Micropogonias undulatus*, and threadfin shad, *Dorosoma petenense*, each at 2%; and blue catfish, *Ictalurus furcatus*, at 1%. All other species (54) comprised 5% of the total weight. Corresponding CPUE (kg/h) were 16.1 for white shrimp, 5.4 for penaeid shrimp, 2.7 for Gulf menhaden, 2.2 for blue crab, 1.8 for discarded penaeid shrimp, 0.9 for debris, 0.7 for Atlantic croaker, 0.6 for threadfin shad, and 0.4 for blue catfish.

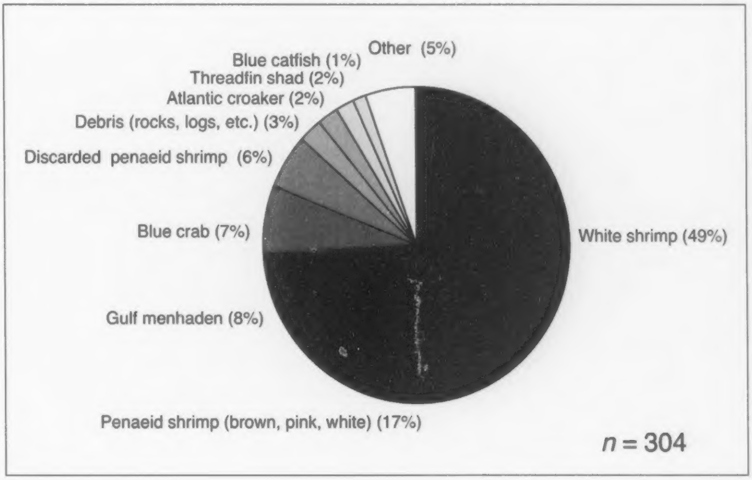

Figure 5.—Percent species composition by weight from skimmer trawl tows.

From number extrapolations, species composition samples for both years, all areas, seasons, and depths (Fig. 6) denote that white shrimp comprised 61% of the total catch, followed by penaeid shrimp at 28%, Gulf menhaden at 4%, and discarded penaeid shrimp and Atlantic croaker each at 2%. Debris counts accounted for less than 1% based on one unit of debris for each tow. All other species (57) comprised 4% of the total number. CPUE in number per hour

were 4,475 for white shrimp, 2,016 for penaeid shrimp, 291 for Gulf menhaden, 118 for discarded penaeid shrimp, and 112 for Atlantic croaker.

Estimated CPUE by Year and Season

Figure 7 depicts CPUE estimates (kg/h) by season and year. Catch rates of penaeid shrimp were higher compared with other species categories for both years and seasons. The highest estimated catch rate of penaeid shrimp was observed from May through August 2005 (23.6 kg/h); CPUE was lower in September through December 2004 (21.0 kg/h). Fish CPUE was higher in September through December 2004 (6.5 kg/h) as compared with May through August 2005 (5.1 kg/h). Nonpenaeid shrimp crustacean catch rate was highest from May through August 2005 (3.3 kg/h), followed by September through December 2004 (1.9 kg/h). Debris estimated CPUE was similar between years and seasons with the highest catch rate from May through August 2005 (1.0 kg/h) followed by September through December 2004 (0.8 kg/h). CPUE of discarded penaeid shrimp was highest from September through December 2004 (2.1 kg/h) as compared with May through August 2005 (0.8 kg/h). Noncrustacean invertebrate CPUE was less than 1.0 kg/h for both seasons.

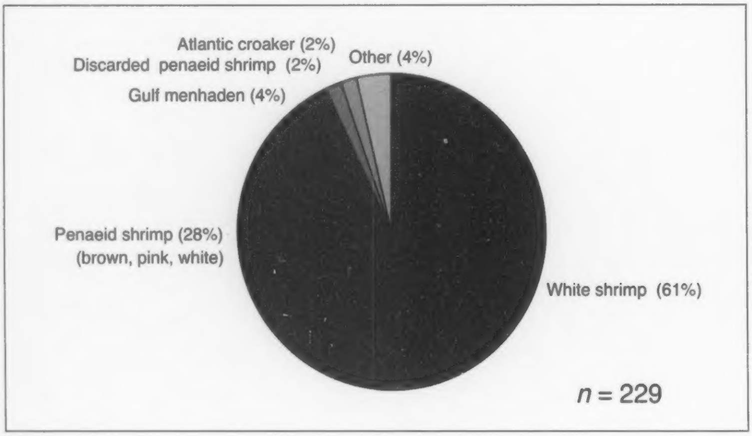

Figure 6.—Percent species composition by number from skimmer trawl tows. Percentage does not equal 100% due to rounding.

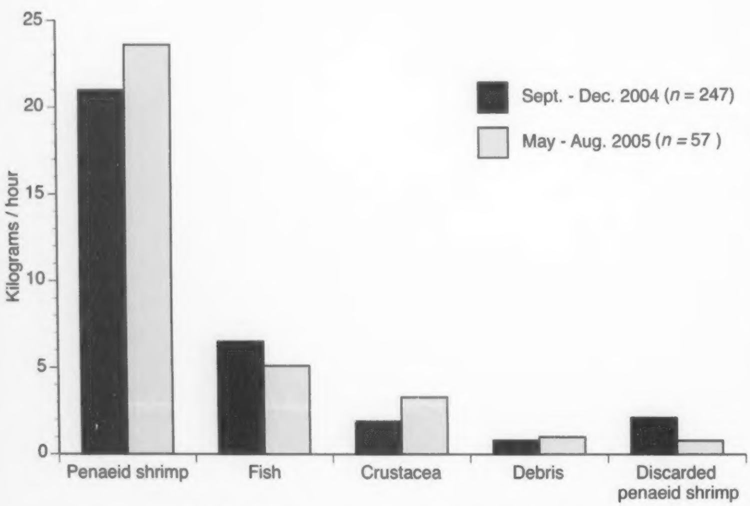

Figure 7.—CPUE (kg/h) by year, season, weight, and category from skimmer trawl tows.

Sea Turtle Interactions

Restricted tow times are established by individual states based on the potential for sea turtle interactions. During the study period, no sea turtles were captured.

Discussion

From September 2004 through June 2005, data from about 307 tows were collected during 96 trips (114 sea days) aboard three skimmer-trawl vessels in coastal Louisiana. Vessel and fishing characteristics were documented. Overall vessel length averaged 39.7 ft. All vessels were of fiberglass construction and had ice hold capacity. Two nets were pushed on each vessel, each with a headrope length of 16 ft. Tow time averaged 1.7 h. The average fishing depth was 1.3 fathoms, with a mean towing speed of 1.8 kn.

Vessel selection was opportunistic, and may not be representative of the entire fleet. Moreover, as reported by Hein and Meier (1995), the use of skimmer trawls is prevalent throughout coastal Louisiana. Our study was restricted to two generalized areas in Louisiana.

From nonextrapolated data, penaeid shrimp (heads-on) constituted 61% of the total weight; corresponding CPUE (kg/h) was 20.2. Extrapolated data from species composition samples yielded slightly higher estimates. Penaeid shrimp accounted for 66% of the total catch; CPUE (kg/h) was 21.6.

Similarly, based on extrapolated data, finfish accounted for 19% of the total weight, followed by crustaceans at 7%, discarded penaeid shrimp at 6%, and

debris at 3%. Corresponding CPUE (kg/h) was 6.2 for finfish, 2.2 for crustaceans, 1.8 for discarded penaeid shrimp, and 0.9 for debris.

Compared with previous studies conducted in North Carolina (Coale et al. 1994; Hines et al. 1999), our study yields substantially higher penaeid shrimp and lower finfish CPUE. This may be attributed to higher shrimp production in Louisiana than in North Carolina, alternate gear designs, variable fishing practices, or a combination of all these factors.

The discards to landings ratio was 0.63 for the skimmer trawl fishery in our study. This was notably less than the ratio of 4.56 reported by Harrington et al. (2005) for the Gulf of Mexico otter-trawl fishery.

In our study, the dominant species by weight were white shrimp, followed by other penaeid shrimp species, Gulf menhaden, blue crab, discarded penaeid shrimp, debris, Atlantic croaker, threadfin shad, and blue catfish. By number, the dominant species were white shrimp, followed by other penaeid shrimp species, Gulf menhaden, discarded penaeid shrimp, and Atlantic croaker.

Seasonally, higher penaeid shrimp CPUE occurred from May through August 2005 compared with September through December 2004. This pattern was also observed for nonpenaeid shrimp crustacean and debris. For finfish and discarded penaeid shrimp, CPUE was higher from September through December 2004 compared with May through August 2005. In conclusion, bycatch rates in this study were substantially lower in skimmer trawls compared with historical and current estimates of bycatch associated with capture from otter trawls. Based on these findings and previous studies (Coale et al., 1994; Hines et al., 1999), skimmer trawls provide an alternative to conventional otter trawls for harvesting penaeid shrimp. The tangible benefits include, but are not limited to, reducing finfish bycatch, lessening bottom habitat disruption, and decreasing fuel consumption. Subsequent shrimp yield based on size (i.e. growth overfishing), potential sea turtle interactions, and other abiotic and biotic interactions warrant further investigation, and should be considered when assessing the optimal approach to resource management.

Acknowledgments

We first commend the outstanding efforts given by the fishery observers involved in this research effort and the commercial fishing industry members who seek to make a difference in the management of the resource by allowing observers onboard. Linda Guidry was an invaluable asset in locating participants and for logistical support. We sincerely thank Dennis Koi for all his help with the data entry system and summarization of data files. Estella Garcia has devoted many long hours of outstanding work in data entry.

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Testing a Device to Exclude Ovigerous Blue Crabs, *Callinectes sapidus*, from Commercial Pots

PAUL J. RUDERSHAUSEN and MARC J. TURANO

Introduction

The blue crab, *Callinectes sapidus*, provides the most economically important fishery in North Carolina (NCDMF, 2004) but population trends have raised concerns among fishery managers. Eggleston et al. (2004) documented a significant spawning stock-recruitment relationship, and trends in biomass decline, increasing fishing mortality, and decreasing mean size of mature females during 1987–2001. Because female crabs have a terminal molt and small mature females may continually escape through cull rings, fishing mortality may decrease their average size and subsequent recruitment in North Carolina (Wolcott and Wolcott, 2004). For these reasons, fishery managers have set a goal to maintain the stock at a level that maximizes reproductive potential (NCDMF, 2004).

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Brooding female (sponge) crabs can be legally harvested in North Carolina. Since 1965, North Carolina has used five spawning sanctuaries to protect mature female crabs in the vicinity of inlets between the Atlantic Ocean and Pamlico and Core Sounds (Fig. 1). Owing to seasonal and annual fluctuations in salinity, as well as their small area, sanctuaries appear to offer minimal protection to the North Carolina blue crab spawning stock (Medici, 2004). Fishery managers in North Carolina have recently expressed interest in investigating other methods to protect the sponge crab population short of an outright prohibition against their harvest (NCDMF, 2004).

ABSTRACT—North Carolina fishery managers are considering methods to offer greater protection to the blue crab, Callinectes sapidus, *spawning stock while maintaining a viable commercial fishery for female blue crabs in high salinity estuaries. We tested how effectively wire rectangles, or excluders, of two internal sizes, 45x80 mm and 45x90 mm, would prevent entry of ovigerous female (sponge) crabs into pots relative to control pots (without excluders) while maintaining sizes and catch rates of male and nonsponged female hard crabs. Field sampling among three pot designs (two excluder sizes and control pots) was conducted in Core Sound, N.C., during 2004–06. Median sizes (carapace widths) of mature female crabs were not different among the three pot types. However, median sizes of male crabs and sponge crabs were greater in control pots than pots with either size of excluder. Catch rates of mature female crabs from control pots were greater than from pots with 45x85 mm excluders. Catch rates of legal male and sponge crabs from control pots were greater than from pots with either size of excluder. Results indicate that using excluders involves a tradeoff between reducing catches and sizes of sponge crabs while also reducing sizes and catches of legally harvestable nonsponge crabs; moreover, the reduction in total catch and sizes would be greater for legal male crabs than for legal nonsponged female crabs. In high salinity waters close to North Carolina's existing no-harvest blue crab sanctuaries, where females typically dominate catches of hard crabs, the benefit of using excluders to prevent entry of sponge crabs may outweigh a potentially modest decrease in landings of nonsponged females.*

Effective protection of sponge crabs may increase the reproductive potential for blue crabs in North Carolina; this species currently has a stock status of "concern" in the state (NCDMF[1]). There are several reasons to investigate efficient, inexpensive methods to reduce capture rates of sponge crabs in the North Carolina commercial pot fishery instead of simply prohibiting their harvest. Depending on location and time of year, sponge crabs have relatively little or no market value. As such, they are often discarded at sea or landed at low-value (cull) market grades (Paul J. Rudershausen, personal observ.). The capture and subsequent release of sponge crabs can affect their brood sizes and migrations. Sponge crabs mutilate their broods while held in pots (Rittschof, 2004), but the impact of sponge crab confinement on reproductive potential has not been quantified. Prohibiting the harvest of sponge crabs would affect crab fishermen along the Outer Banks, where these crabs can constitute 25% or more of the harvest (Ballance and Ballance, 2003).

The effectiveness of a device to exclude sponge crabs but permit entry of nonsponged crabs rests on the fact that these two groups have different body proportions. A similar premise has been used to effectively exclude diamondback terrapins, *Malaclemys terrapin*, from crab pots (Guillory and Prejean, 1998). A partially or fully developed egg mass will result in a functionally greater body length (inter-orbital teeth to the back of

[1]NCDMF. 2006. Stock status of important coastal fisheries in North Carolina, 2006. Available online at http://www.ncfisheries.net/stocks/bluecrab.htm.

the apron) and body depth of a sponge crab relative to a male or nonsponged mature female of roughly equal carapace width (Fig. 2). Blue crabs enter pots in a direction parallel to their carapace width such that this dimension is perpendicular to the face of the opening that the crab enters (Guillory and Merrell, 1993). Thus, the body length and depth of a blue crab will determine whether it fits through the opening of a crab pot. The development of the egg mass can prevent entry of a sponge crab into a pot with a restrictive opening, depending on the size of the opening, size of the crab, fullness of the sponge, and motivation of the crab to enter the pot.

Our objective was to identify one or more excluder sizes that would simultaneously reduce sizes and numbers of sponge crabs relative to control pots while maintaining sizes and numbers of nonsponged crabs. If effective at preventing the entry of sponge crabs into pots, excluders would increase reproductive potential of the blue crab population through at least three processes: 1) reduce levels of harvest, 2) reduce stress (such as brood scrubbing) and limb loss to sponge crabs that fishermen elect not to harvest, and 3) eliminate a barrier to sponge crabs migrating to offshore waters to release their broods. In theory, a barrier to entry, such as an excluder, would only need to be applied in the high salinity portions of estuaries where sponge crabs are typically found.

Eldridge et al. (1979) believed that the effectiveness of culling devices affixed to crab pots depended on satisfying three criteria; they are inexpensive and easy to affix, they reduce catches of non-target crabs, and they maintain catches of target crabs. These criteria were considered in assessing the utility of sponge crab excluders as a means to protect blue crab broodstock in North Carolina waters.

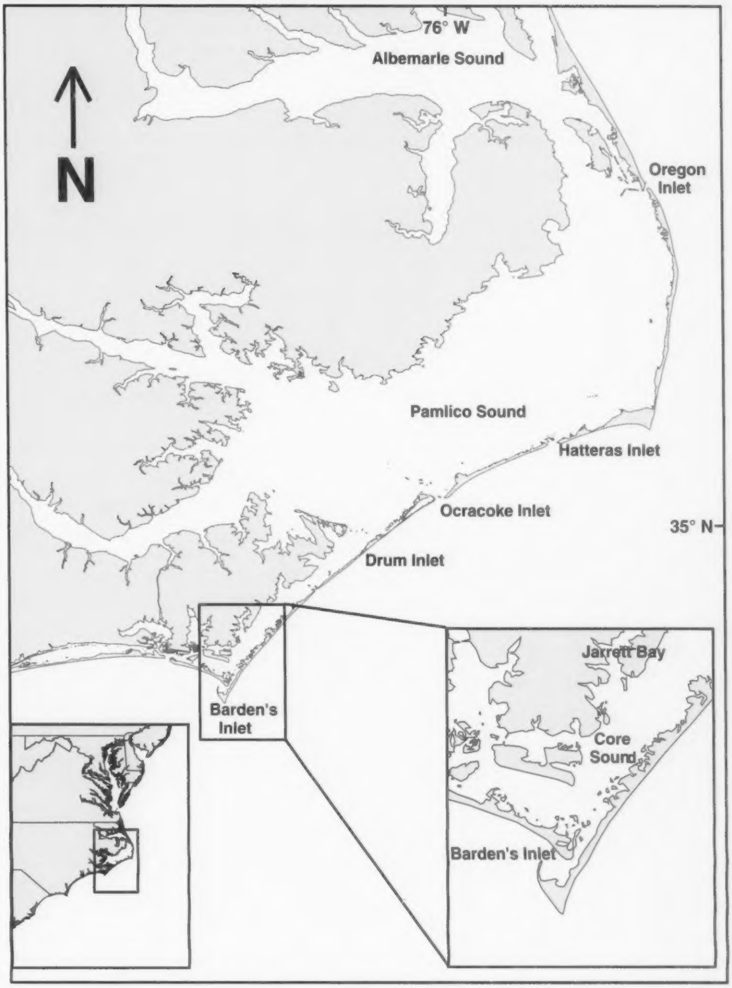

Figure 1.— The field sampling area, Jarrett Bay and lower Core Sound, N.C. Oregon, Hatteras, Ocracoke, Drum, and Barden's Inlets represent the five blue crab spawning sanctuaries in North Carolina.

Methods

Potentially effective excluder sizes were determined from trials conducted in spring, 2004 by holding hard crabs in shedding tanks. Seven sizes of rectangular excluders were tested: 52×105, 50×100, 50×95, 50×90, 45×90, 45×80, and 40×80 mm (internal dimensions). Excluders were constructed from 12-gauge stainless steel, with four of the same size attached with wire hog clips to the four funnel entrances of each of seven pots (Fig. 3). Each pot soaked for tank trials was baited with previously frozen Atlantic menhaden, *Brevoortia tyrannus*.

Pots were submerged into tanks that measured 2 m long, 0.75 m wide, and 0.4 m deep, which covered the funnel entrances of pots. Ten tagged, variably sized crabs of each type (legal male (>127 mm carapace width), mature female, and sponge) were introduced in turn into a tank containing a single pot. The status (entry vs. non-entry) of each crab was recorded every 4 h for 24 h. A second 24 h trial was repeated for each type and excluder size using ten new crabs. From these tank experiments, two excluder sizes were selected for comparisons in field trials: 45×90

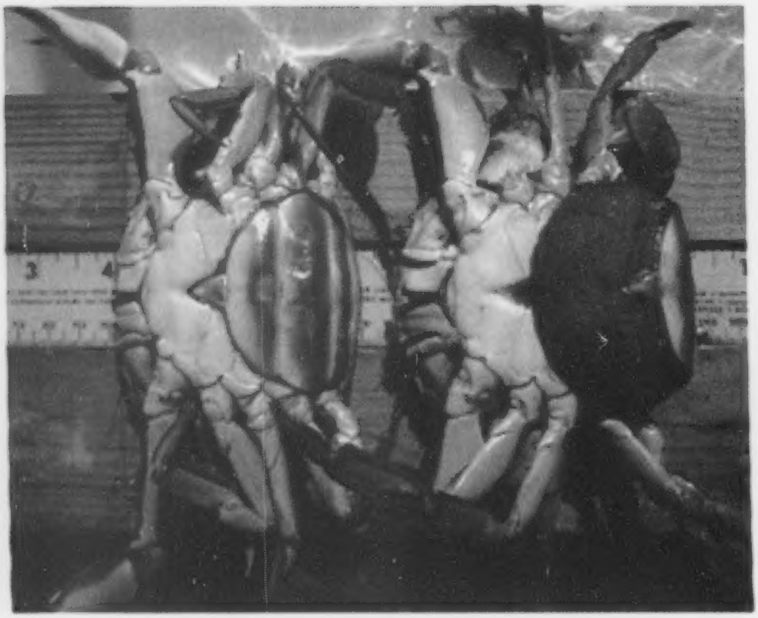

Figure 2.—Mature nonsponged female (left) and sponged female crab (right). The brood effectively increases the body length (distance from interorbital teeth to back of the apron) and dorsal-to-ventral body depth.

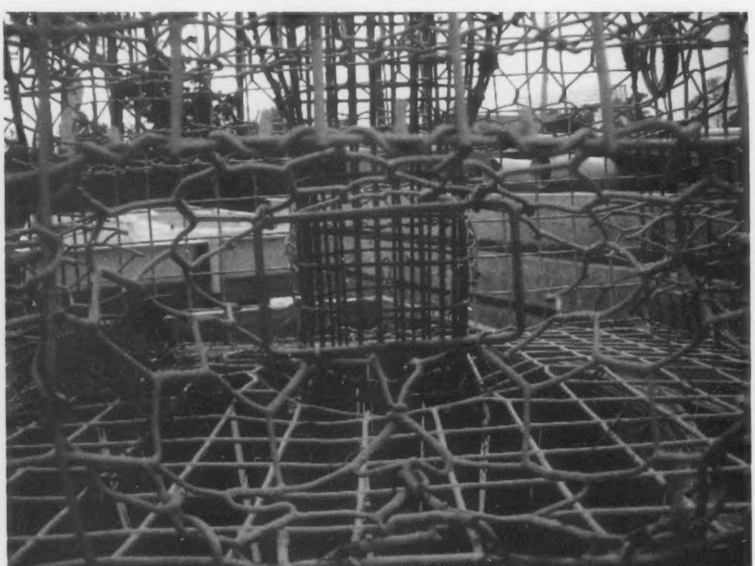

Figure 3.—Excluder attached to a funnel entrance of a pot set for hard crabs. Photograph is taken from the outside the funnel entrance looking inward through the stainless-steel excluder into the bottom chamber of the pot. The small-mesh bait well is in the background.

and 45×85 mm. Smaller excluders prevented entry of a high percentage of nonsponged crabs while larger excluders allowed entry of a high percentage of sponge crabs.

Pots with excluders were fished alongside control pots (no excluders) from 2004–06. All field trials were conducted in Jarrett Bay and adjacent lower Core Sound, a mesohaline estuary west of North Carolina's Outer Banks (Fig. 1). Lower Core Sound lies close to (~10 km from) Barden's Inlet, one of the five North Carolina blue crab spawning sanctuaries. Salinity in this estuary varies widely as a function of wind and rainfall (Paul J. Rudershausen, personal observ.). In 2004 (May–November), pots were deployed over a range of salinities (10–30‰) (upper Jarrett Bay–lower Core Sound) in order to capture male, female, and sponge crabs in a range of sizes. In 2005 (April–June) and 2006 (May–June), we made an effort to deploy pots in higher salinities (Core Sound) to capture a greater number of sponge crabs. All pots were made of 38.1 mm vinyl-coated square mesh that had two legally mandated 58.7 mm escape (cull) rings affixed to the middle of opposing sides of the upper chamber of each pot.

Pots were baited with fresh or frozen fish, deployed sequentially (varying treatments), and soaked for durations ranging from 24–96 h. Within each sampling period, all pots were soaked for the same duration. The 2004 field sampling consisted of fishing 36 pots (before pot loss) on each of 40 days. The 2005 sampling fished 60 pots on each of 20 days, and the 2006 sampling fished 30 pots in each of 20 days.

Upon retrieval of each pot, each crab was identified (male, mature female, immature female, and sponge) and measured (carapace width, body length, and body depth, mm). Male crabs were separated by size (legal vs. sub-legal). Female crabs were separated by level of maturity (mature vs. immature; North Carolina seasonally prohibits harvest of immature female crabs of certain sizes). Brood color (a proxy for brood stage) and percent fullness (nearest 25%) were recorded for sponge crabs.

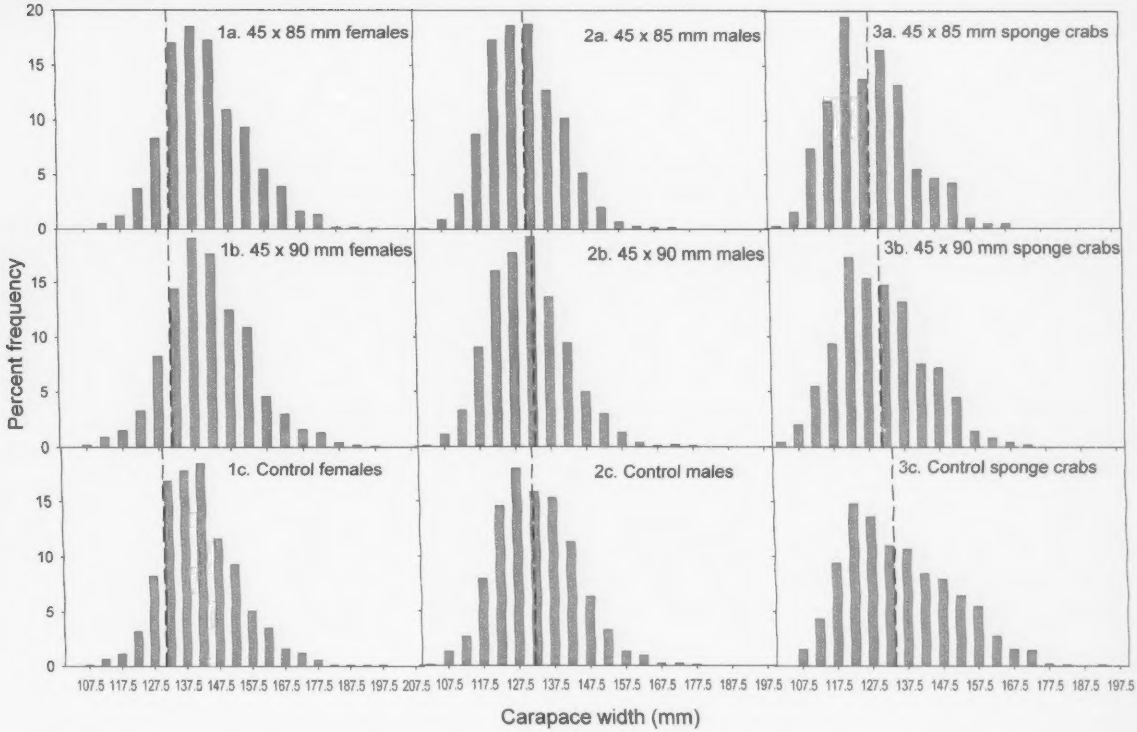

Figure 4.—Carapace width frequency histograms and median carapace widths (vertical dashed lines) of mature female (1), all male (2), and sponge crabs (3) from pots with 45×85 mm excluders (a), 45×90 mm excluders (b), and control pots (c) tested during 2004–06.

Carapace width, body length, and body depth (mm) were measured on each crab ≥ 59 mm body length. Crabs that were less than 59 mm body length (less than the diameter of the cull rings) were not included in the analysis because early in the field work they were often observed escaping through the cull rings as pots were being pulled.

Owing to the high variability on the catches of each category of legally harvestable crabs (mature female, legal male, and sponge), catch-per-pot (catch-per-unit-effort (CPUE)) comparisons among treatments for each crab type were conducted using the nonparametric Kruskal-Wallis test. Post-hoc multiple comparisons were performed in those cases when the Kruskal-Wallis test statistic was significant.

Due to the non-normality of crab size (carapace width) data, widths of mature female, all male (legal and sub-legal), and sponge crabs were compared among treatments using a median test, a nonparametric pairwise ranks test that employs a chi-square test statistic.

Body length and depth measurements were used to determine the percentage of crabs in each of three categories (female, legal male, and sponge) that were too large to fit through each of the two excluder sizes tested in field trials.

Results

A total of 1,061 control pots, 1,027 pots with 45×90 mm excluders, and 1,015 pots with 45×85 mm excluders were fished. Median and mean carapace widths of mature female crabs were similar among treatments (Fig. 4; Table1). There were no significant pairwise differences in the median carapace width of mature female crabs between treatments (Table 2). Excluders had a more pronounced effect on widths of male than female crabs (Fig. 4; Table1). Each excluder treatment caught significantly smaller male crabs than the control, although there was no difference among the two excluder treatments (Table 2). Excluders also had a pronounced effect on the widths of sponge crabs (Fig. 4; Table 1). Each excluder treatment caught significantly smaller median sized sponge crabs than the control, although there was no difference among the two excluder treatments (Table 2).

The analysis of catch-per-pot data indicated that larger openings permitted the entry of greater numbers of mature female, legal male, and sponge crabs (Table 3). Pots with 45×90 mm excluders, but not pots with 45×85 mm excluders, maintained mean catch rates of mature females relative to control pots (Krukal-Wallis H=10.19; p=0.070) (Fig. 5a, Table 4). Pots with each size

Table 1.—Median and mean (±S.E.) carapace width (mm) of mature female, all male, and sponge crabs among three pot treatments tested during 2004–06.

Measurement	Treatment	Mature female	Male	Sponge
Median	45×85 mm excluder	141	131	129
	45×90 mm excluder	141	133	131
	Control	141	132	134
Mean	45×85 mm excluder	141.90±0.25	131.52±0.23	130.06±0.59
	45×90 mm excluder	141.91±0.24	131.68±0.22	131.59±0.55
	Control	142.21±0.23	132.86±0.21	135.72±0.53

Table 2.—Chi-square test statistics and significance levels (α= 0.05) of multiple comparisons tests of median carapace width of mature female, all male, and sponge crabs among three pot treatments tested during 2004–06.

Crab type	Treatment ↓ →	45×85 mm excluder	45×90 mm excluder
Mature female	45×85 mm excluder		
	45×90 mm excluder	1.08; 0.299	
	Control	0.71; 0.400	0.04; 0.841
Male	45×85 mm excluder		
	45×90 mm excluder	0.25; 0.614	
	Control	14.18; 0.0001	8.07; 0.005
Sponge	45×85 mm excluder		
	45×90 mm excluder	4.02; 0.045*	
	Control	15.81; <0.0001	9.85; 0.002

of excluder caught significantly less legal male crabs than control pots (H =26.05; p=0.001) (Fig. 5b; Table 4). Similar results were observed for the mean number of sponge crabs caught (H =49.09; p<0.001) (Fig. 5c; Table 4).

Crabs from control pots were assumed to represent the sizes of crabs in the Core Sound population (no negative size selectivity). Measurements of mature female crabs from control pots from 2004–06 showed that 0.5% had a body length and/or depth that exceeded the 45×85 and 45×90 mm excluders. Measurements of legal male crabs from control pots show that 0.7% had a body length and/or depth that exceeded the 45×85 and 45×90 mm excluders. Lastly, measurements of sponge crabs from control pots show that 13.4% had a body length and/or depth that exceeded the 45×85 mm excluder while 7.2% had a body length and/or depth that exceeded the 45×90 mm excluder.

Table 3.—Mean catch-per-pot (±S.E.) of mature female, legal male (≥127 mm carapace width), and sponge crabs among three pot treatments tested during 2004–06.

Treatment	Mature female	Legal male	Sponge
45×85 mm excluder	2.27±0.10	1.43±0.07	0.38±0.03
45×90 mm excluder	2.40±0.10	1.50±0.07	0.48±0.03
Control	2.57±0.10	1.86±0.08	0.77±0.05

Discussion

Three years of sampling in Core Sound indicates that, depending on spring salinities and weather, the potential exists for crab pots with excluders to reduce entry of sponge crabs relative to those without excluders (control pots). In this experiment, control pots had a significantly greater catch rate of sponge crabs than pots with either size of excluder. Sampling also demonstrated that pots with excluders could not maintain catch rates of both mature female and legal male crabs while concurrently reducing catch rates of sponge crabs. Further, when using excluders, sizes of both mature female and legal male crabs could not be maintained while also reducing sizes of sponge crabs. While some crabs can pass through an excluder of an equal or smaller size than their body length and/or depth, the field data we collected also indicates that a restrictive opening the same size or slightly (mm) larger than a crab's body length and/or depth will deter some non-sponge crabs trying to enter pots.

Only a small percentage of sponge crabs from control pots had body lengths and/or depths that would theoretically prevent them from entering pots with 45×85 (13.4% prevented entry) and 45×90 mm excluders (7.2% prevented entry) (Fig. 6). (It is assumed that

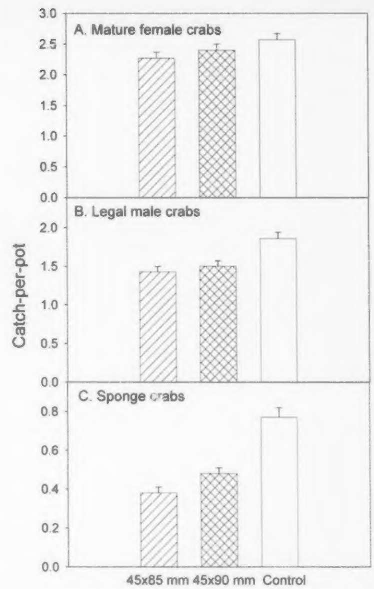

Figure 5.—Mean catch-per-pot (± S.E.) of mature female (a), legal male (b), and sponge crabs (c) among three pot treatments tested during 2004–06.

Table 4.—Significance levels (α= 0.05) of multiple comparisons tests of mean catch-per-pot of mature female, legal male (≥127 mm carapace width), and sponge crabs among three pot treatments tested during 2004–06.

Crab type	Treatment ↓ →	45×85 mm excluder	45×90 mm excluder
Mature female	45×85 mm excluder		
	45×90 mm excluder	0.888	
	Control	0.018	0.268
Legal male	45×85 mm excluder		
	45×90 mm excluder	0.660	
	Control	<0.0001	0.006
Sponge	45×85 mm excluder		
	45×90 mm excluder	0.954	
	Control	<0.0001	0.0002

the funnel opening of a control pot (~150×100 mm) is sufficiently large that it does not bias the size of sponge crabs entering it). While sampling closer to Barden's Inlet or one of the other four inlet blue crab sanctuaries in North Carolina may have yielded different percentages of sponge crabs that would theoretically be prevented entry by using excluders, it is assumed that the size distribution of sponge crabs approximates that of the population from other waters close to spawning sanctuaries. While the percentage of sponge crabs prevented entry from excluder-equipped pots is low, reducing the excluder size to prevent entry of a larger percentage of sponge crabs would (in the minds of commercial fishermen) prevent entry of an unacceptably high percentage of nonsponged legal crabs. Sponge crabs prevented entry by either 45×85 or 45×90 mm excluders would be among the most fecund in the population; a sponge crab 180 mm carapace width, for example, has a brood with roughly three times the number of eggs as a sponge crab 120 mm carapace width (NCDMF, 2004). Since a female crab can produce up to five broods in the same season (Rittschof, 2004), the disproportionately greater egg production by larger females, and protection of these female, have benefits over multiple broods.

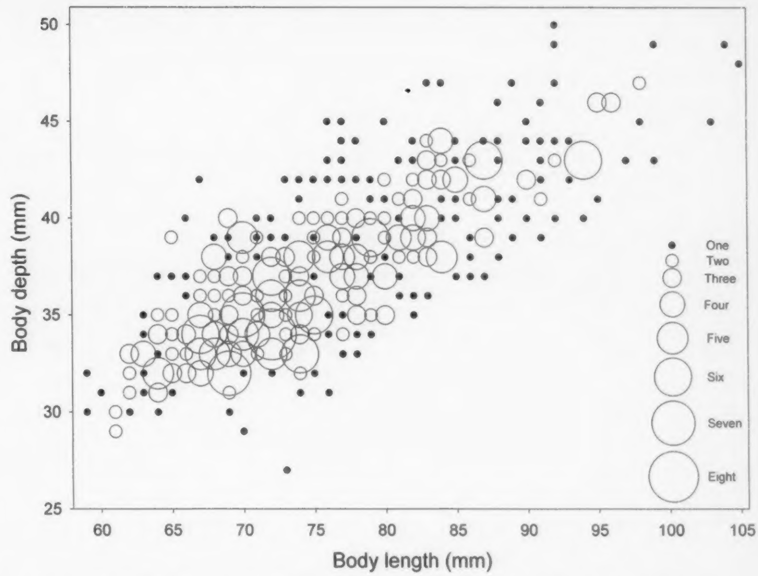

Figure 6.—Body lengths and depths (mm) of sponge crabs with full broods (estimated 100%) from control pots. Color (black or white) and size of each mark denotes the number of sponge crabs that had this body length and depth.

According to a recently developed model of sponge crab emigration from nearby Newport River (NC) estuary (Rittschof, 2002), sponge crabs caught in Core Sound are carrying their first broods. Thus, harvest of sponge crabs in North Carolina estuaries eliminates not only release of the first brood, but production and release of subsequent broods as well. Field work from studying excluders indicates that the reproductive potential of blue crab broodstock may also be impacted by brood scrubbing when sponge crabs become stressed from confinement in pots. Of sponge crabs that had broods in the early stages of development (yellow or orange sponges) when a rounded sponge should be observed, 31.7% had broods with a scrubbed appearance. Rather than naturally releasing some of their brood, many crabs with orange or yellow sponges likely were stressed in pots to the point that they began to scrub (Rittschof, 2004). Additionally, field work for the excluder study revealed that 28% of sponge crabs had brown or black broods. Given that sponge crabs release their broods in coastal (not estuarine) waters (Rittschof, 2002), it appears that sponge crabs are being caught as they emigrate from estuaries. Thus, the reproductive potential of sponge crabs may be impacted through harvest and capture that stresses the crab (brood scrubbing) or delays its migration offshore.

Success of using excluders as a management tool to protect sponge crabs rests on two premises: 1) male and female crabs are variably distributed by salinity, and 2) fishermen would be satisfied that specific areas where excluders are required have sufficiently few male crabs that the sizes and catch rates of nonsponged hard crabs (primarily nonsponged females) could be maintained. In the study area, the composition of the hard crab catch abruptly switched from males to females with increasing distance from land (or marsh) (increasing depth) and also proximity to Barden's Inlet (increasing salinity). While the catch was not examined on an area-by-area basis, these observations indicate that using excluders in high salinity waters close to inlets would have little impact on catches of males, because relatively few are found there. Indeed, the differential salinity preferences between male and female crabs creates a relatively low natural abundance of males in the vicinity of inlet sanctuaries, and a correspondingly low expectation by commercial fishermen that large numbers of males would be found there. The comparative catch data between excluder sizes also shows that using excluders of the largest size we tested (45x90 mm) would have no statistical impact on catch rates of nonsponged females compared to pots without excluders (control).

The seasonal abundance of sponge crabs is sufficiently brief and the area where they are found in abundance sufficiently small that excluders could have a positive effect if used over short periods and in specific locations. Of course, North Carolina already has time and area closures to protect sponge crabs, in the

form of its five spawning sanctuaries that prohibit crab potting and trawling during seasons (spring/summer) of greatest sponge crab abundance. The effectiveness of North Carolina's five blue crab sanctuaries remains unclear. In 2005 sampling, sponge crabs represented 29% of our total catch despite our relatively long distance (~12 km) from the nearest sanctuary, Barden's Inlet. Medici (2004) postulated that a spatially and temporally dynamic, rather than static, sanctuary program would allow managers the flexibility to protect sponge crabs during times when, and in areas where, they are most abundant. These areas of highest sponge crab concentration before they leave estuaries would likely shift westward during drought years and seaward during years of high rainfall (Medici, 2004).

Because of their construction from 12-gauge stainless steel, each excluder was relatively expensive ($2.60, 2004 price). The cost of outfitting an entire pot with excluders from stainless would be a likely impediment to their acceptance among commercial fishermen. However, high-density polyethylene (HDPE) (for example) can be molded to form excluders of precise sizes and relatively inexpensive prices (~$0.30 each, 2004 price). HDPE excluders attached externally to funnel entrances, such as done in studies of interactions between diamondback terrapins and crab pots (Cahoon and Hart 2004), can greatly decrease the time required to affix or remove them.

This analysis of excluders as devices to prevent entry of sponge crabs to pots while allowing entry of nonsponged crabs demonstrates that excluders of any one size are not highly effective at preventing entry of sponge crabs. The largest openings tested (control pots) allowed the greatest rates of capture of both sponge and nonsponged crabs. Conversely, the smallest excluder tested prevented entry of a high percentage of sponge crabs (relative to control pots) but also prevented entry of a high number of nonsponged hard crabs. Rather than a physical barrier such as excluders, a yet-to-be-tested chemical device may hold greater promise of preventing entry of sponge crabs in high salinity environments where their protection is sought.

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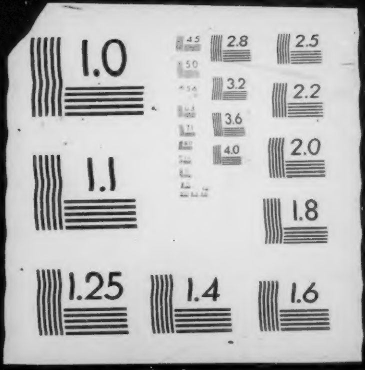
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